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Environmental Technology Verification Protocol

Drinking Water Systems Center

PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR PHYSICAL REMOVAL OF MICROBIOLOGICAL AND PARTICULATE CONTAMINANTS

Prepared by

NSF International

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

EPA/NSF ETV
PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR PHYSICAL REMOVAL OF MICROBIOLOGICAL AND PARTICULATE CONTAMINANTS

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Environmental Technology Verification Program

U.S. ENVIRONMENTAL PROTECTION AGENCY

Throughout its history, the U.S. Environmental Protection Agency (EPA) has evaluated technologies to determine their effectiveness in preventing, controlling, and cleaning up pollution. EPA is now expanding these efforts by instituting a new program, the Environmental Technology Verification Program---or ETV---to verify the performance of a larger universe of innovative technical solutions to problems that threaten human health or the environment. ETV was created to accelerate the entrance of new environmental technologies into the domestic and international marketplace. It supplies technology buyers and developers, consulting engineers, states, and U.S. EPA regions with high quality data on the performance of new technologies. This encourages more rapid availability of approaches to better protect the environment.

ETV Drinking Water Systems Center

Concern about drinking water safety has accelerated in recent years due to much publicized outbreaks of waterborne disease and information linking ingestion of arsenic to cancer incidence. The EPA is authorized through the Safe Drinking Water Act (SDWA) to set numerical contaminant standards and treatment and monitoring requirements that will ensure the safety of public water supplies. However, small communities are often poorly equipped to comply with all of the requirements; less costly package treatment technologies may offer a solution. These package plants can be designed to deal with specific problems of a particular community; additionally, they may be installed on site more efficiently---requiring less start-up capital and time than traditionally constructed water treatment plants. The opportunity for the sales of such systems in other countries is also substantial.

The EPA has partnered with NSF International (NSF) to verify performance of small drinking water systems that serve small communities. It is expected that both the domestic and international markets for such systems are substantial. The EPA and NSF have formed an oversight stakeholders group composed of buyers, sellers, and states (issuers of permits), to assist in formulating consensus testing protocols. A goal of verification testing is to enhance and facilitate the acceptance of small drinking water treatment equipment by state drinking water regulatory officials and consulting engineers while reducing the need for testing of equipment at each location where the equipment use is contemplated. NSF will meet this goal by working with equipment manufacturers and other agencies in planning and conducting equipment verification testing, evaluating data generated by such testing, and managing and disseminating information. The manufacturer is expected to secure the appropriate resources to support its part of the equipment verification process, including provision of equipment and technical support.

The verification process established by the EPA and NSF is intended to serve as a template for conducting water treatment verification tests that will generate high quality data for verification of equipment performance. The verification process can help in moving small drinking water equipment into routine use more quickly. The verification of an equipment's performance involves five sequential steps:

1. Development of a Product Specific Test Plan (PSTP);
2. Execution of verification testing;
3. Data reduction, analysis, and reporting;
4. Performance and cost factor (labor, chemicals, energy) verification; and
5. Report preparation and information transfer.

This verification testing program is being conducted by NSF with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development (ORD), National Risk Management Research Laboratory (NRMRL), Water Supply and Water Resources Division (WSWRD) - Cincinnati, Ohio. NSF's role is to provide technical and administrative leadership and support in conducting the testing. It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations.

Partnerships
The EPA and NSF cooperatively organized and developed the ETV Drinking Water Systems (DWS) Center to meet community and commercial needs. NSF and the Association of State Drinking Water Administrators (ASDWA) have an understanding to assist each other in promoting and communicating the benefits and results of the project.

NSF INTERNATIONAL

Mission Statement
NSF, an independent, non-governmental organization, is dedicated to being the leading global provider of public health and safety-based risk management solutions while representing the interest of all stakeholders.

NSF Purpose and Organization
NSF is an independent not-for-profit organization. For more than 52 years, NSF has been in the business of developing consensus standards that promote and protect public health and the environment and providing testing and certification services to ensure manufacturers and users alike that products meet those standards. Today, millions of products bear the NSF Name, Logo and/or Mark symbols upon which the public can rely for assurance that equipment and products meet strict public health and performance criteria and standards.

Limitations of use of NSF Documents
This protocol is subject to revision; contact NSF to confirm this revision is current. The testing against this protocol does not constitute an NSF Certification of the product tested.

ORGANIZATION AND INTENDED USE OF PROTOCOL AND TEST PLANS

NSF encourages the user of this protocol to also read and understand the policies related to the verification and testing of drinking water treatment systems and equipment.

The first chapter of this document describes the protocol required in all studies verifying the performance of equipment or systems removing microbiological and particulate contaminants. The remaining chapters, or Technology Specific Test Plans (TSTPs), describe the additional requirements for equipment and systems using specific technologies to attain the goals and objectives of the protocol: the removal of microbiological and particulate contaminants.

Prior to the verification testing of drinking water treatment systems, plants and/or equipment, the equipment manufacturer and/or supplier must select an NSF-qualified, Field Testing Organization (FTO). This designated FTO must write a PSTP to define the testing plan specific to the product. The equipment manufacturer and/or supplier will need this protocol and the TSTP(s) contained herein and possibly other ETV protocols and TSTPs to develop the PSTP, depending on the treatment technologies used in the unit processes or treatment train of the equipment or system. More than one protocol and/or TSTP may be necessary to address the equipment's capabilities in the treatment of drinking water.

Testing shall be conducted by an NSF-qualified FTO that is selected by the manufacturer. Water quality analytical work to be completed as a part of a TSTP shall be contracted with a laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the U.S. EPA. For information on a listing of NSF-qualified FTOs and state, third-party, or the U.S. EPA-accredited laboratories, contact NSF.

ACKNOWLEDGMENTS

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CHAPTER 1

EPA/NSF ETV
PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR PHYSICAL REMOVAL OF MICROBIOLOGICAL AND PARTICULATE CONTAMINANTS

REQUIREMENTS FOR ALL STUDIES

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INTRODUCTION

This document is the protocol to be used for verification testing of equipment designed to achieve physical removal of microbiological and particulate contaminants. The equipment Field Testing Organization (FTO) is requested to adhere to the requirements of this protocol in developing a Product Specific Test Plan (PSTP).

The testing of new technologies and materials that are unfamiliar to NSF International (NSF) and/or the U.S. Environmental Protection Agency (EPA) will not be discouraged. It is recommended that resins or membranes or any other material or chemical in the equipment conform to NSF/American National Standards Institute (ANSI) Standard 60 and 61.

The final submission of the PSTP shall:

- Include the information requested in this protocol;
- Conform to the format identified herein; and
- Conform to the specific Environmental Technology Verification (ETV) Technology Specific Test Plan(s) [TSTP(s)] related to the manufacturer's statement(s) of performance capabilities that are to be verified.

The PSTP may incorporate the requirements of more than one TSTP. For example, testing might be undertaken to verify performance of a system employing coagulation and filtration for removal of microbiological and particulate contaminants and for removal of disinfection byproduct precursors.

This protocol document is presented in two fonts. The non-italicized font provides the rationale for the requirements and background information that the FTO may find useful in preparation of the PSTP. *The italicized text indicates specific protocol deliverables that are required of the FTO or of the manufacturer and that must be incorporated in the PSTP.*

The following glossary terms are presented here for subsequent reference in this protocol:

- Distribution System - A system of conduits by which a primary water supply is conveyed to consumers typically by a network of pipes.

- EPA - The United States Environmental Protection Agency, its staff or authorized representatives.

- Equipment - Testing equipment for use in the verification testing program which may be defined as either a package plant or modular system.

- Field Testing Organization (FTO) - An organization qualified to conduct studies and testing of drinking water treatment systems in accordance with protocols and TSTPs. The role of the FTO is to complete the application on behalf of the company; to ensure preparation of an acceptable PSTP; to enter into contracts with NSF, as discussed herein, arrange for or conduct the skilled operation of equipment during the intense period of testing during the study and the tasks required by the protocol.

- Manufacturer - A business that assembles and/or sells package plant equipment and/or modular systems. The role of the manufacturer is to provide the package plant and/or

modular system and technical support for the verification testing and study. The manufacturer is also responsible for providing assistance to the FTO during operation and monitoring of the package plant or modular system during the verification testing and study.

- Modular System - A packaged functional assembly of components for use in a drinking water treatment system or packaged plant that provides a limited form of treatment of the feedwater(s) and which is discharged to another module of the package plant or the final step of treatment to the distribution system.

- NSF - NSF International, its staff, or other authorized representatives.

- Package Plant - A complete water treatment system including all components from connection to the raw water(s) through discharge to the distribution system.

- Plant Operator - The person working for a small water system who is responsible for operating water treatment equipment to produce treated drinking water. This person also may collect samples, record data and attend to the daily operations of equipment throughout the testing periods.

- Product Specific Test Plan (PSTP) - A written document of procedures for on-site/in-line testing, sample collection, preservation, and shipment and other on-site activities described in the EPA/NSF ETV protocol(s) and TSTP(s) that apply to a specific make and model of a package plant/modular system.

- Protocol - A written document that clearly states the objectives, goals and scope of the study as well as the TSTP(s) for the conduct of the study. Protocol shall be used for reference during manufacturer participation in the verification testing program.

- Report - A written document that includes data, test results, findings, and any pertinent information collected in accordance with a protocol, analytical methods, procedures, etc., in the assessment of a product whether such information is preliminary, draft or final form.

- Technology Specific Test Plan (TSTP) - A written document that describes the procedures for conducting a test or study for the application of water treatment technology. At a minimum, the TSTP will include detailed instructions for sample and data collection, sample handling and sample preservation, precision, accuracy, statistical uncertainty, and quality assurance and quality control (QA/QC) requirements.

- Testing Laboratory - An organization certified by a third-party independent organization, federal agency, or a pertinent state regulatory authority to perform the testing of drinking water samples. The role of the testing laboratory in the verification testing of drinking water treatment equipment is to analyze the water samples in accordance with the methods and meet the pertinent QA/QC requirements described in the protocol, TSTP and PSTP.

- Verification - To establish the evidence on the range of performance of equipment and/or device such as a package plant or modular system under specific conditions following a predetermined protocol(s) and TSTP(s).

- Verification Statement - A written document that summarizes a final report reviewed and approved by NSF on behalf of the EPA or directly by the EPA.

- Water System - The water system that operates water treatment equipment to provide treated water to its customers.

1.1 Objectives

The specific objectives of verification testing may be different for each drinking water treatment system, depending upon the statement of performance capabilities of the specific equipment to be tested. The manufacturer's performance capabilities are used to establish data quality objectives (DQOs) to develop the experimental design of the verification test. The broader the performance capabilities, the more comprehensive the PSTP must be to achieve the DQOs. The objectives developed by each manufacturer shall be defined and described in detail in the PSTP developed for each piece of equipment. The objectives of the equipment verification testing may include:

- Generation of field data appropriate for verifying the performance of the equipment, and
- Evaluation of new advances in equipment and equipment design.

An important aspect in the development of the verification testing is to describe the procedures that will be used to verify the statement of performance capabilities made for water treatment equipment. A PSTP document incorporates the QA/QC elements needed to provide data of appropriate quality sufficient to reach a defensible position regarding the equipment performance.

1.2 Scope

This protocol outlines the verification process for equipment designed to achieve the physical removal of microbiological and particulate contaminants. The scope of this protocol includes TSTPs for systems employing coagulation and filtration, for microfiltration (MF), for diatomaceous earth filtration, and for other technologies for physical removal of particulates and microbial contaminants.

An overview of the verification process and the elements of the PSTP to be developed by the FTO are described in this protocol. Specifically, the PSTP shall define the following elements of the verification testing:

- Roles and responsibilities of verification testing participants;
- Procedures governing verification testing activities such as equipment operation and process monitoring; sample collection, preservation, and analysis; and data collection and interpretation (see Section 5.0 - Field Operations Procedures);
- Experimental Design (see Section 4.0);
- QA/QC procedures for conducting the verification testing and for assessing the quality of the data generated from the verification testing; and,
- Health and safety measures relating to biohazard (if present), electrical, mechanical and other safety codes.

Content of PSTP:

The structure of the PSTP must conform to the outline below: The required components of the document shall be described in greater detail in the sections below.

- *TITLE PAGE*
- *FOREWORD*
- *TABLE OF CONTENTS - The Table of Contents for the PSTP shall include the headings provided in this document although they may be modified as appropriate for a particular type of equipment to be tested.*
- *EXECUTIVE SUMMARY - The Executive Summary describes the contents of the PSTP (not to exceed two pages). A general description of the equipment and the statement of performance capabilities which shall be verified during testing shall be included, as well as the testing locations, a schedule, and a list of participants.*
- *ABBREVIATIONS AND ACRONYMS - A list of the abbreviations and acronyms used in the PSTP shall be provided.*
- *EQUIPMENT VERIFICATION TESTING RESPONSIBILITIES (described in the sections below)*
- *EQUIPMENT CAPABILITIES AND DESCRIPTION (described in the sections below)*
- *EXPERIMENTAL DESIGN (described in the sections below)*
- *FIELD OPERATIONS PROCEDURES (described in the section below)*
- *QUALITY ASSURANCE PROJECT PLAN (described in the section below)*
- *DATA MANAGEMENT AND ANALYSIS (described in the section below)*
- *SAFETY PLAN (described in the section below)*

2.0 EQUIPMENT VERIFICATION TESTING RESPONSIBILITIES

2.1 Verification Testing Organization and Participants

The required content of the PSTP and the responsibilities of participants are listed at the end of each section. In the development of a PSTP, a manufacturer and its designated FTO shall provide a table which includes the name, affiliation, and mailing address of each participant, a point of contact, their role, and telephone, fax and E-mail address.

The equipment provided by the manufacturer shall explicitly meet all the requirements of Occupational Safety and Health Association (OSHA), National Electrical Manufacturers Association (NEMA), Underwriters Laboratory (UL), NSF and other appropriate agencies to ensure operator safety during verification testing.

2.2 Organization

The organizational structure for the verification testing showing lines of communication shall be provided by the FTO in its application on behalf of the manufacturer.

2.3 Verification Testing Site Name and Location

This section discusses background information on the verification testing site(s), with emphasis on the quality of the feedwater, which in some cases may be the source water at the site. The PSTP must provide the site names and locations. In most cases, the equipment may be demonstrated at more than one site. In all cases, the equipment should be tested under different feedwater quality (or source water quality) and seasonal weather and climate conditions.

2.4 Site Characteristics

The PSTP must include a description of the test site. This shall include a description of where the equipment will be located. If the feed water is the source water for an existing water treatment plant, describe the raw water intake, the opportunity to obtain raw water without the addition of any chemicals as feedwater to the equipment being tested, the pattern of operation of the raw water pumping (is it continuous or intermittent?), and facilities for handling treated water and waste (i.e., residuals) from the testing. For water filtration testing, can the water flows appropriate for the equipment being tested be dealt with in an acceptable way? Are water pollution discharge permits needed? Source water characteristics shall be documented.

2.5 Responsibilities

This section identifies the organizations involved in the testing and describes the primary responsibilities of each organization. The responsibilities of the manufacturer may vary depending on the type of verification testing. Multiple manufacturer testing at one time is also an option.

In brief, the FTO shall be responsible for:

- Preparation of the PSTP;
- Providing needed logistical support, establishing a communication network, scheduling and coordinating the activities of all verification testing participants;
- Ensuring that locations selected as test sites have feedwater quality consistent with the objectives of the verification testing [manufacturer may recommend a verification testing site(s)];
- Managing, evaluating, interpreting, and reporting on data generated by the verification testing; and
- Evaluating and reporting on the performance of the technologies.

The manufacturer shall be responsible for provision of the equipment to be evaluated.

Content of PSTP Regarding Equipment Verification Testing Responsibilities:

The FTO, shall be responsible for including the following elements in the PSTP:

- *Definition of the roles and responsibilities of appropriate verification testing participants;*
- *A table which includes the name, affiliation, and mailing address of each participant, a point of contact, their role, and telephone, fax and E-mail address;*
- *Organization of operational and analytical support;*
- *List of the site name(s) and location(s); and*

- *Description of the test site(s), the site characteristics and identification of where the equipment shall be located.*

In brief, the manufacturer shall be responsible for:

- Provision of complete, field-ready equipment for verification testing;
- Provision of logistical, and technical support, as required;

- Provision of technical assistance to the qualified FTO during operation and monitoring of the equipment undergoing verification testing;
- Reviewing the PSTP; and
- Reviewing the verification report.

3.0 EQUIPMENT CAPABILITIES AND DESCRIPTION

3.1 Equipment Capabilities

The manufacturer and its designated FTO must provide the water quality objectives to be achieved in the statement of performance capabilities of the equipment to be evaluated in the verification testing. The manufacturer's performance capabilities are used to establish DQOs to develop the experimental design of the verification test. The broader the performance capabilities, the more comprehensive the PSTP must be to achieve the DQOs. Statements should also be made regarding the applications of the equipment, what advantages it provides over existing equipment and the known limitations of the equipment. The statement of performance capabilities must be specific and be verifiable by a statistical analysis of the data. An example of a satisfactory statement of performance capabilities would be:

> "This system is capable of pretreating and filtering feedwaters characterized by 100 nephelometric turbidity units (NTU) and producing filtered water with a turbidity equal to or less than 0.20 NTU in 95 percent of the filtered water samples collected during a filter run."

A statement of performance capabilities such as:

> "This system will provide lower turbidity than required by the Surface Water Treatment Rule on a consistent and dependable basis,"

would not be acceptable.

The statement of performance capabilities shall indicate the range of water quality with which the equipment can be challenged while successfully treating the feedwater. Statements of performance capabilities that are too easily met may not be of interest to the potential user, while performance capabilities that are overstated may not be achievable. The statement of performance capabilities forms the basis of the entire equipment verification testing and must be chosen appropriately. Therefore, the design of the PSTP shall include a sufficient range of feedwater quality to permit verification of the statement of performance capabilities.

3.2 Equipment Description

Description of the equipment for verification testing shall be included in the PSTP. Data plates shall be permanent and securely attached to each production unit. The data plate shall be easy to read in English or the language of the intended user, located on the equipment where it is readily accessible, and contain at least the following information:

- Equipment Name;
- Model #;
- Manufacturer's name and address;
- Electrical requirements - volts, amps, and Hertz;
- Serial Number;
- Warning and Caution statements in legible and easily discernible print size; and
- Capacity or output rate (if applicable).

Content of PSTP Regarding Equipment Capabilities and Description:

The PSTP shall include the following:

- *Description of the equipment to be demonstrated including photographs from relevant angle or perspective;*
- *Brief introduction and discussion of the engineering and scientific concepts on which the water treatment equipment is based;*
- *Description of the treatment train and each unit process included in the equipment including all relevant schematics;*
- *Brief description of the physical construction/components of the equipment, including the general environmental requirements and limitations, weight, transportability, ruggedness, power and other consumables needed, etc;*
- *Statement of typical rates of consumption of chemicals, a description of the physical and chemical nature of wastes, and rates of waste production concentrates, residues, etc.;*
- *Definition of the performance range of the equipment;*
- *Identification of any special licensing requirements associated with the operation of the equipment;*
- *Description of the applications of the equipment and the removal capabilities of the treatment system relative to existing equipment by providing comparisons in such areas as: treatment capabilities, requirements for chemicals and materials, power, labor requirements, suitability for process monitoring and operation from remote locations, ability to be managed by part-time operators; and*
- *Discussion of the known limitations of the equipment by including such items as the range of feedwater quality suitable for treatment with the equipment, the upper limits for concentrations of contaminants that can be removed to concentrations below desired levels, and level of operator skill required to successfully use the equipment.*

4.0 EXPERIMENTAL DESIGN

This section discusses the objectives of the verification testing, factors that must be considered to verify the performance capabilities, and the statistical and other means that the FTO should use to evaluate the results of the verification testing.

4.1 Objectives

The objectives of this verification testing are to evaluate equipment in the following areas:

- Performance relative to manufacturer's stated range of equipment capabilities;
- Impacts of variations in feedwater quality (such as turbidity, particle concentration, temperature, pH, alkalinity, etc.);
- Logistical, human, and economic resources necessary to operate the equipment; and
- Reliability, ruggedness, cost factors, range of usefulness, and ease of operation.

The PSTP shall include those treatment tests listed in TSTPs that are most appropriate to challenge the drinking water treatment system. For example, if equipment is only intended for removal of *Giardia* and *Cryptosporidium*, there would be no need to conduct testing to evaluate the removal of color.

4.2 Equipment Characteristics

This section discusses factors that shall be considered in the design and implementation of the verification testing. These factors include:

- Ease of operation;
- Degree of operator attention required;
- Response of equipment and treatment process to changes in feedwater quality;
- Electrical requirements;
- System reliability features including redundancy of components;
- Feed flow requirements;
- Discharge requirements;
- Spatial requirements for the equipment (footprint);
- Unit processes included in treatment train; and
- Chemicals needed.

Verification testing procedures shall simulate routine conditions as much as possible and in most cases, testing may be done in the field; hence, in that circumstance, simulation of field conditions would not be necessary.

4.2.1 Qualitative Factors

Some factors, while important, are difficult or impossible to quantify. These are considered qualitative factors. Important factors that cannot easily be quantified are the modular nature of the equipment, the safety of the equipment, the portability of equipment, and the logistical requirements necessary for using it.

Typical qualitative factors to be discussed are listed below, and others may be added. The PSTP shall discuss those factors that are appropriate to the test equipment, including:

- Reliability or susceptibility to adverse environmental conditions;
- Equipment safety; and
- Effect of operator experience on treatment results.

4.2.2 Quantitative Factors

Many factors in this verification testing can be quantified by various means. Some can be measured while others cannot be controlled. Typical quantitative factors to be discussed are listed below, and others may be added. The PSTP shall discuss those factors that are appropriate to the test equipment, including:

- Power and consumable supply (such as chemical) requirements;
- Cost factors of operation, expendables, and waste disposal (such as labor hours and quantity of waste generated); and
- Length of operating cycle.

These quantitative factors shall be used as an initial benchmark to assess equipment performance.

4.3 Water Quality Considerations

Water treatment equipment is used to treat water and change the quality of feedwater (or raw water) so it meets manufacturer's performance capabilities. In addition, the treated water should be aesthetically pleasing and palatable. The experimental design shall be developed so the relevant questions about water treatment equipment objectives can be answered.

Equipment manufacturers should recognize that it is highly unlikely that any single item of water treatment process equipment can successfully treat any conceivable feedwater containing all of the regulated contaminants and produce a treated water that meets the quality requirements for every regulated contaminant. Although multiple processes could be placed in a treatment train to accomplish such a goal, for most public water systems such comprehensive treatment capability is not needed and would not be cost effective. Therefore, drinking water treatment has been focused on the water quality aspects of concern for particular locations.

The range of contaminants or water quality problems that can be addressed by water treatment equipment varies, and some treatment equipment can address a broader range of problems than other types. Manufacturers should carefully consider the capabilities and limitations of their equipment and have PSTPs prepared that challenge their product sufficiently to provide data for a broad market. FTOs shall use TSTPs as the basis for preparation of the specific PSTPs.

4.3.1 Feedwater Quality

One of the key aspects related to water treatment equipment performance verification is the range of feedwater quality that can be treated successfully, resulting in treated water quality that meets water quality objectives or regulatory requirements. The manufacturer and FTO should consider the influence of feedwater quality on the quality of treated waters produced

by the equipment, such that product waters meet the water quality objectives or regulatory requirements. As the range of feedwater quality that can be treated by the equipment becomes broader, the potential applications for treatment equipment with verified performance capabilities may also increase.

One of the questions often asked by regulatory officials in approval of water treatment equipment is "Has it been shown to work on the water where you propose to put it?" By covering a large range of water qualities, the verification testing is more likely to provide an affirmative answer to that question.

The FTO shall specify in the PSTP the specific water quality parameters to be monitored during testing. The following feedwater quality characteristics may be important for treatment equipment intended to remove microbiological and particulate contaminants:

- Turbidity and particle concentration;
- Temperature, with temperatures near freezing having potential for the most difficult treatment conditions;
- Dissolved organic carbon (DOC), total organic carbon (TOC), or UV-254 absorbance;
- Biological dissolved organic carbon (BDOC) or assimilable organic carbon (AOC);
- Color;
- Density (concentration) of microorganisms (*Giardia, Cryptosporidium*, bacteria, viruses);
- pH and alkalinity;
- Iron and manganese;
- Total dissolved solids (TDS);
- Bromide and ammonia; and
- Presence of algae, particularly filter clogging algae.

Specific water quality parameters required for each technology addressed in this protocol are outlined in the TSTPs (Chapters 2 through 6).

4.3.2 Treated Water Quality

Treated water quality is very important. If a manufacturer's statement of performance capabilities states that water treatment equipment can be used to treat water to meet specified requirements, the verification testing must provide data that support such a statement of capabilities. In addition, the manufacturer may wish to make a statement about performance capabilities of the equipment for removal of other contaminants.

Furthermore, some water treatment equipment can be used to meet aesthetic objectives. Water quality considerations that may be important for some small systems include:

- Color, taste and odor;
- TDS; and
- Iron and manganese.

Finally, other water quality parameters are useful for assessing equipment performance. These may include:

- Particle count or concentration;
- Heterotrophic plate count (HPC) bacteria; and
- BDOC or AOC.

The manufacturer and FTO are encouraged to address these factors in the design of the verification testing program.

4.4 Recording Data

For all particulate and microbiological contaminant removal experiments, data should be maintained on the pH, temperature and other water quality parameters listed in Sections 4.3.1 and 4.3.2 above. The following items of information shall also be maintained for each experiment:

- Type of chemical addition, dose and chemical combination, where applicable (e.g., alum, cationic polymer, anionic polymer, ozone, monochloramine, scale inhibitor, etc.);
- Water type (raw water, pretreated feedwater, product water, waste water); and
- Experimental run (e.g. 1st run, 2nd run, 3rd run, etc.).

4.5 Recording Statistical Uncertainty

For the analytical data obtained during verification testing, 95% confidence intervals shall be calculated by the FTO for water quality parameters in which eight or more samples were collected. The PSTP shall specify which water quality parameters shall be subjected to the requirements of confidence interval calculation. DQOs and the vendor's statement of performance capabilities shall be used to assess which water quality parameters are critical and thus require confidence interval statistics. As the name implies, a confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. The following formula shall be employed for confidence interval calculation:

$$\text{confidence interval} = \overline{X} \pm t_{n-1,1-\frac{\alpha}{2}} \left(S / \sqrt{n} \right)$$

where: X is the sample mean;
S is the sample standard deviation;
n is the number of independent measurements included in the data set;
t is the Student's t distribution value with n-1 degrees of freedom; and
α is the significance level, defined for 95% confidence as: 1 - 0.95 = 0.05.

According to the 95% confidence interval approach, the α term is defined to have the value of 0.05, thus simplifying the equation for the 95% confidence interval in the following manner:

$$\text{95\% confidence interval} = \overline{X} \pm t_{n-1,0.975} \left(S / \sqrt{n} \right)$$

With input of the analytical results for pertinent water quality parameters into the 95% confidence interval equation, the output will appear as the sample mean value plus or minus the second term.

The results of this statistical calculation may also be presented as a range of values falling within the 95% confidence interval. For example, the results of the confidence interval calculation may provide the following information: 520 +/- 38.4 mg/L, with a 95% confidence interval range described as (482, 558).

Calculation of confidence intervals shall not be required for equipment performance results (e.g., filter run length, cleaning efficiency, in-line turbidity or in-line particle counts, etc.) obtained during the equipment testing verification program. However, as specified by the FTO, calculation of confidence intervals may be required for such analytical parameters as grab samples of turbidity, TOC, DOC. To provide sufficient analytical data for statistical analysis, the FTO shall collect a minimum of eight discrete water samples at one set of operational conditions for each of the specified water quality parameters during a designated testing period. The procedures and sampling requirements shall be provided in detail in the PSTP.

4.6 Verification Testing Schedule

Verification testing activities include equipment set-up, initial operation, verification operation, and sampling and analysis. Initial operations are intended to be conducted so equipment can be tested to be sure it is functioning as intended. If feedwater (or source water) quality influences operation and performance of equipment being tested, the initial operations period serves as the shake-down period for determining appropriate operating parameters. The schedule of testing may also be influenced by coordination requirements with a utility.

For water treatment equipment involving coagulation and filtration for control of microbiological and particulate contaminants, an initial period of bench-scale testing (jar testing) followed by treatment equipment operation may be needed to determine the appropriate coagulant chemical type and dosages, as well as the pH values of coagulated water that will result in successful functioning of the process train. Procedures for jar testing are provided in the American Water Works Association's (AWWA) Manual M37, "Operational Control of Coagulation and Filtration Processes."

A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary to verify the manufacturer's statement of performance capabilities, such as in the treatment of surface water where additional testing during each season may assist in verifying an objective. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst case concentrations of contaminants which can verify the manufacturer's statement of performance capabilities. For example, good challenge conditions for a system which reduces microbiological and particulate contaminants might be cold temperatures (1^{o} to 5^{o}C), which can have an adverse affect on some water treatment processes due to the increase in water viscosity at cold temperatures. Cold temperature considerations may be particularly important for membrane filtration applications.

Although one testing period satisfies the minimum requirement of the ETV Program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Content of PSTP Regarding Experimental Design:

The PSTP shall include the following elements:

- *Identification of the qualitative and quantitative factors of equipment operation to be addressed in the verification testing program;*
- *Identification and discussion of the water treatment problem or problems that the equipment is designed to address, how the equipment will solve the problem, and who would be the potential users of the equipment;*
- *Identification of the range of key water quality parameters, given in applicable TSTPs, which the equipment is intended to address and for which the equipment is applicable;*
- *Identification of the key parameters of treated water quality that shall be used for evaluation of equipment performance during the physical removal of microbiological and particulate contaminants. Parameters of significance for treated water quality were listed above in Section 4.3.2. and in applicable TSTPs;*
- *Description of the confidence interval calculation procedure for selected water quality parameters; and*
- *Detailed outline of the verification testing schedule, with regard to testing periods that will cover an appropriate range of annual climatic conditions, (i.e., different temperature conditions, seasonal differences between rainy and dry conditions).*

5.0 FIELD OPERATIONS PROCEDURES

5.1 Equipment Operations and Design

The TSTP specifies procedures that shall be used to ensure the accurate documentation of both water quality and equipment performance. Careful adherence to these procedures will result in definition of verifiable performance of equipment. (Note that this protocol may be associated with a number of different TSTPs for different types of physical removal process equipment.)

Design aspects of water treatment process equipment often provide a basis for approval by state regulatory officials and can be used to ascertain if process equipment intended for larger or smaller flows involves the same operating parameters that were relevant to the verification testing. Specific design aspects to be included in the PSTP are provided in detail.

5.2 Communications, Documentation, Logistics, and Equipment

The successful implementation of the verification testing will require detailed coordination and constant communication between all verification testing participants. All field activities shall be thoroughly documented. Field documentation will include field logbooks, photographs, field data sheets, and chain-of-custody forms. The FTO shall be responsible for maintaining all field documentation. The following guidelines shall be followed:

- Field notes shall be kept in a bound logbook;
- Field logbooks shall be used to record all water treatment equipment operating data;
- Each page shall be sequentially numbered;
- Each page shall be labeled with the project name and number;
- Completed pages shall be signed and dated by the individual responsible for the entries; and
- Errors shall have one line drawn through them and this line shall be initialed and dated.

All photographs shall be logged in the field logbook. These entries shall include the time, date, direction, subject of the photograph, and the identity of the photographer. Any deviations from the approved final PSTP shall be thoroughly documented in the field logbook at the time of inspection and in the verification report.

Original field sheets and chain-of-custody forms shall accompany all samples shipped to the analytical laboratory. Copies of field sheets and chain-of-custody forms for all samples shall be provided at the time of the QA/QC inspection and included in the verification report.

5.3 Initial Operations

Initial operations will allow equipment manufacturers to refine their operating procedures and to make operation adjustments as needed to successfully treat the feedwater. Information generated through this period of operation may be used to revise the PSTP, if necessary. A failure at this point in the verification testing could indicate a lack of capability of the process equipment and the verification testing might be canceled.

5.4 Equipment Operation and Water Quality Sampling for Verification Testing

All field activities shall conform to requirements provided in the PSTP that was developed and approved for the verification testing being conducted. If unanticipated or unusual situations are encountered that may alter the plans for equipment operation, water quality sampling, or data quality, the situation shall be discussed with the verification entity. Any deviations from the approved final PSTP shall be thoroughly documented.

During routine operation of water treatment equipment, the following items should be documented and described by the qualified FTO, the water system, or the plant operator:

- Total number of hours during which the equipment was operated each day;
- Number of hours each day during which the operator was working at the treatment plant and performing tasks related to water treatment and the operation of the treatment equipment; and
- Tasks performed during equipment operation.

Content of PSTP Regarding Field Operations Procedures:

The PSTP shall include the following elements:

- *A table summary of the proposed time schedule for operating and testing;*
- *Field operating procedures for the equipment and performance testing, based upon the TSTP with listing of operating parameters, ranges for feedwater quality, and the sampling and analysis strategy;*
- *Provision of all equipment needed for field work associated with this verification testing;*
- *Provision of a complete list of all equipment to be used in the verification testing. A table format is suggested;*
- *Provision of field operating procedure; and*
- *At a minimum, a table(s) showing all parameters to be analyzed, the analytical methods, the laboratory reporting limits or quantification limits, sample volume, bottle type, preservation method, and holding times.*

6.0 QUALITY ASSURANCE PROJECT PLAN

Every PSTP for verification testing must include a Quality Assurance Project Plan (QAPP) that specifies procedures that shall be used to ensure data quality and integrity. Careful adherence to these procedures will ensure that data generated from the verification testing will provide sound analytical results that can serve as the basis for performance verification.

6.1 Purpose and Scope

The purpose of this section is to outline steps that shall be taken by operators of the equipment and by the analytical laboratory to ensure that data resulting from this verification testing is of known quality and that a sufficient number of critical measurements are taken.

6.2 Quality Assurance Responsibilities

A number of individuals may be responsible for monitoring equipment operating parameters and for sampling and analysis QA/QC throughout the verification testing. Primary responsibility for ensuring that both equipment operation and sampling and analysis activities comply with the QA/QC requirements of the PSTP (Section 6) shall rest with the FTO.

QA/QC activities for the analytical laboratory that analyzes samples sent off-site shall be the responsibility of that analytical laboratory's supervisor. If problems arise or any data appear unusual, they shall be thoroughly documented and corrective actions shall be implemented as specified in this section. The QA/QC measurements made by the off-site analytical laboratory are dependent on the analytical methods being used.

6.3 Data Quality Indicators

The data obtained during the verification testing must be of sound quality for conclusions to be drawn on the equipment. For all measurement and monitoring activities conducted for equipment verification, the NSF and EPA require that data quality parameters be established based on the proposed end uses of the data. Data quality parameters include five indicators of data quality: representativeness, completeness, accuracy, precision, and statistical uncertainty.

Treatment results generated by the equipment must be verifiable for the purposes of this program to be fulfilled. High quality, well documented analytical laboratory results are essential for meeting the purpose and objectives of this verification testing. Therefore, the following indicators of data quality shall be closely evaluated to determine the performance of the equipment when measured against data generated by the analytical laboratory.

6.3.1 Representativeness

Representativeness refers to the degree to which the data accurately and precisely represent the conditions or characteristics of the parameter represented by the data. In this verification testing, representativeness will be ensured by executing consistent sample collection procedures, including sample locations, timing of sample collection, sampling procedures, sample preservation, sample packaging, and sample shipping. Representativeness also will be ensured by using each method at its optimum capability to provide results that represent the most accurate and precise measurement it is capable of achieving.

For equipment operating data, representativeness entails collecting a sufficient quantity of data during operation to be able to detect a change in operations. For most water treatment processes involving microbiological and particulate contaminant removal, detecting a +/- 10 percent change in an operating parameter (e.g. headloss) is sufficient. Mixing energies and flows shall be recorded on a daily basis to track changes in operational conditions that exceed this 10 percent range.

6.3.2 Completeness

Completeness refers to the amount of data collected from a measurement process compared to the amount that was expected to be obtained. Completeness refers to the proportion of valid, acceptable data generated using each method. This portion of the required data for the selected test plan will be reported at the conclusion of each testing period.

The completeness objective for data generated during verification testing is based on the number of samples collected and analyzed for each parameter and/or method. The test plans will likely require a large number of samples to be collected for key and most important parameters and/or methods. The following chart illustrates the completeness objectives for performance parameter and/or method based on the sample frequency:

Number of Samples Per Parameter and/or Method	Percent Completeness
0-10	80%
11-50	90%
>50	95%

Completeness is defined as follows for all measurements:

$$\%C = (V/T) \times 100$$

where: %C = percent completeness;
V = number of measurements judged valid; and
T = total number of measurements.

Additional testing and collection of additional sample will be required if the percent completeness objectives are not met. If the completeness objectives are still not met through the collection of additional samples, then a retest will be required.

The following are examples of instances that might cause a sample analysis to be incomplete:

- Instrument failure;
- Calibration requirement not being met; and
- Elevated analyte levels in the method blank.

6.3.3 Accuracy

For water quality analyses, accuracy refers to the difference between an experimentally determined sample result and the accepted reference value for the sample. Analytical accuracy is a measure of analytical bias due to systematic errors. Loss of accuracy can be caused by such processes as errors in standards preparation, equipment calibrations, loss of target analyte in the extraction process, interferences, and systematic or carryover contamination from one sample to the next.

In this verification testing, the FTO will be responsible for maintaining consistent sample collection procedures, including sample locations, timing of sample collection, sampling procedures, sample preservation, sample packaging, and sample shipping to maintain a high level of accuracy in system monitoring. The FTO shall discuss the applicable ways of determining the accuracy of the chemical and microbiological samples and analytical techniques in the PSTP.

For equipment operating parameters, accuracy refers to the difference between the reported operating condition and the actual operating condition. For equipment operating data, maintaining a high level of accuracy will require collecting a sufficient quantity of data during operation to be able to detect a change in operations. For water flow, accuracy is the difference between the reported flow indicated by a flow meter and the flow as actually measured on the basis of known volumes of water and carefully defined times (bucket and stopwatch technique) as practiced in hydraulics laboratories or water meter calibration shops. For mixing equipment, accuracy is the difference between an electronic readout for equipment RPMs and the actual measurement based on counted revolutions and measured time. Accuracy of head loss measurement can be determined by using measuring tapes to check the calibration of piezometers for gravity filters or by checking the calibration of pressure gauges for pressure filters. Meters and gauges must be checked periodically for accuracy, and when proven to be dependable over time, the time interval between accuracy checks can be increased. In the PSTP, the FTO shall discuss the applicable ways of determining the accuracy of the operational conditions and procedures.

From an analytical perspective, accuracy represents the deviation of the analytical value from the known value. Since true values are never known in the field, accuracy measurements are made on analysis of QC samples analyzed with field samples. QC samples for analysis shall be prepared with laboratory control samples, matrix spikes and spike duplicates. It is recommended for verification testing that the PSTP include laboratory performance of one matrix spike for determination of sample recoveries. Recoveries for spiked samples are calculated in the following manner:

$$\% \text{ Recovery} = 100 \times (SSR - SR)/SA$$

where: SSR = spiked sample results;
SR = sample result; and
SA = spike amount added.

Recoveries for laboratory control samples are calculated as follows:

% Recovery = 100 x (found concentration)/(true concentration)

For acceptable analytical accuracy under the verification testing program, the recoveries reported during analysis of the verification testing samples must be within control limits, where control limits are defined as the mean recovery plus or minus three times the standard deviation.

6.3.4 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. Analytical precision is a measure of how far an individual measurement may be from the mean of replicate measurements. The standard deviation and the relative standard deviation recorded from sample analyses may be reported as a means to quantify sample precision. The percent relative standard deviation may be calculated in the following manner:

$$\%\text{Relative Standard Deviation} = S(100) / X_{average}$$

where: S = standard deviation and
$X_{average}$ = the arithmetic mean of the recovery values.

Standard Deviation is calculated as follows:

$$\text{Standard Deviation} = \sqrt{\frac{\sum_{i=1}^{n}(X_i - X)^2}{n-1}}$$

Where: X_i = the individual recovery values;
X = the arithmetic mean of then recovery values; and
n = the number of determinations.

For acceptable analytical precision under the verification testing program, the percent relative standard deviation for drinking water samples must be less than 30%. If the data generated during the ETV test does not meet the DQOs defined in this QA/QC section, additional testing and sampling will be required. If the DQOs are still not met through additional testing and the collection of additional samples, then a retest will be required.

6.3.5 Statistical Uncertainty

Statistical uncertainty of the water quality parameters analyzed shall be evaluated through calculation of the 95% confidence interval around the sample mean. Description of the confidence interval calculation is provided in Section 4.5 - Recording Statistical Uncertainty.

6.4 Quality Control Checks

This section describes the QC requirements that apply to both the treatment equipment and the on-site water quality analyses. It also contains a discussion of the corrective action to be taken if the QC parameters fall outside of the evaluation criteria.

The quality control checks provide a means of measuring the quality of data produced. The FTO may not need to use all the ones identified in this section. The selection of the appropriate quality control checks depends on the equipment, the experimental design and the performance capabilities. The selection of quality control checks shall be based on discussions among the manufacturer, the FTO and NSF.

6.4.1 Quality Control for Equipment Operation

This section will explain the methods to be used to check on the accuracy of equipment operating parameters and the frequency with which these quality control checks shall be made. If the quality of the equipment operating data cannot be verified, then the water quality analytical results may be of no value. Because water cannot be treated if equipment is not operating, obtaining valid equipment operating data is a prime concern for verification testing.

An example of the need for QC for equipment operations is an incident of state rejection of test data because the treatment equipment had no flow meter to use for determining engineering and operating parameters related to flow.

6.4.2 Water Quality Data

After treatment equipment is being operated and water is being treated, the results of the treatment are interpreted in terms of water quality. Therefore, the quality of water sample analytical results is just as important as the quality of the equipment operating data. The QAPP must emphasize the methods to be employed for sampling and analytical QA. Analytical methods for on-site and off-site monitoring are presented within each TSTP. If new methods are published and approved or current methods updated, the most current methods shall be used. The important aspects of sampling and analytical QA are given below:

6.4.2.1 Duplicate Samples. Duplicate samples must be analyzed to determine the precision of analysis. The procedure for determining samples to be analyzed in duplicate shall be provided with the frequency of analysis and the approximate number. Duplicate samples must include field duplicates and laboratory duplicates. Field duplicates measure the precision of the overall sampling and analysis procedures. Laboratory duplicates measure the precision associated only with the lab procedures.

6.4.2.2 Method Blanks. Method blanks are used to evaluate analytical method-induced contamination, which may cause false positive results.

6.4.2.3 Spiked Samples. The use of spiked samples will depend on the testing program and the contaminants to be removed. The FTO must specify in the PSTP the procedure and frequency of spiking, as well as acceptance criteria, and actions if criteria are not met.

6.4.2.4 Travel Blanks. Travel blanks should be provided to the analytical laboratory to evaluate travel-related contamination.

6.4.2.5 Performance Evaluation Samples for Water Quality Testing. Performance evaluation samples are samples of unknown concentration prepared by an independent performance evaluation (PE) lab and provided as unknowns to an analyst to evaluate his or her analytical performance. Analysis of PE samples shall be conducted onsite by the FTO and by the offsite laboratory before verification testing is initiated. If recent PE reports from the laboratory are not available, PE samples shall be submitted by the FTO to the analytical laboratory. The control limits for the PE samples will be used to evaluate the FTO's and analytical laboratory's method performance. One kind of PE sample that would be used for on-site QA in most studies performed under this protocol would be a pH PE sample.

A PE sample comes with statistics that have been derived from the analysis of the sample by a number of laboratories using EPA-approved methods. These statistics include a true value of the PE sample, a mean of the laboratory results obtained from the analysis of the PE sample, and an acceptance range for sample values. The analytical laboratory is expected to provide results from the analysis of the PE samples that meet the performance capabilities of the verification testing.

6.5 Data Reduction, Validation, and Reporting

To maintain good data quality, specific procedures shall be followed during data reduction, validation, and reporting. These procedures are detailed below.

6.5.1 Data Reduction

Data reduction refers to the process of converting the raw results from the equipment into concentration or other data in a form to be used in the comparison. The procedures to be used will be equipment and data dependent. The purpose of this step is to provide data which shall be used to verify the statement of performance capabilities. These data shall be obtained from logbooks, instrument outputs, and computer outputs as appropriate. Microorganism data shall be transformed by taking the $\log_{10}$ of the data unless data analysis demonstrates an alternative distribution than a logarithmic distribution.

6.5.2 Data Validation

There are two types of data validation which need to be addressed, field data and laboratory data. For the field data (including data collected from field laboratories):

- The operator shall check the correctness of data acquisition and reduction;
- The field team supervisor or another technical person shall review calculations and inspect laboratory logbooks and data sheets to check accuracy of data recording and sampling;
- Calibration and QC data will be examined by the individual operators and the laboratory supervisor; and

- Laboratory and project managers shall check that all instrument systems are in control and that QA objectives for accuracy, precision, and method detection limits have been met.

For the laboratory data:

- Calibration and QC data will be examined by the individual analysts and the laboratory supervisor; and
- Laboratory managers shall check that all instrument systems are in control and that QA objectives for accuracy, completeness, and method detection limits have been met.

Analytical outlier data are defined as those QC data lying outside a specific QC objective window for precision and accuracy for a given analytical method. Should QC data be outside of control limits:

- The analytical laboratory or field team supervisor will investigate the cause of the problem;
- If the problem involves an analytical problem, the sample will be reanalyzed;
- If the problem can be attributed to the sample matrix, the result will be flagged with a data qualifier; and
- The data qualifier will be included and explained in the final analytical report.

6.5.3 Data Reporting

This section contains a list of the water quality and equipment operation data to be reported. At a minimum, the data tabulation shall list the results for feedwater and treated water quality analyses, the results of any microbiological analyses (log_{10} data transformation) and equipment operating data. All QC information such as calibrations, blanks and reference samples are to be included in an appendix. All raw analytical data shall also be reported in an appendix. All data shall be reported in hard copy and electronically in a common spreadsheet or database format.

6.6 System Inspections

On-site system inspections for sampling activities, field operations, and laboratories may be conducted as specified by the TSTP. These inspections will be performed by the verification entity to determine if the TSTP is being implemented as intended. Separate inspection reports will be completed after the inspections and provided to the participating parties.

6.7 Reports

6.7.1 Status Reports

The FTO shall prepare periodic reports for distribution to pertinent parties, e.g., manufacturer, EPA, and the community where testing is performed. These reports shall discuss project progress, problems and associated corrective actions, and future scheduled activities associated with the verification testing. When problems occur, the manufacturer and FTO project managers shall discuss them and estimate the type and degree of impact, and

describe the corrective actions taken to mitigate the impact and to prevent a recurrence of the problems. The frequency, format, and content of these reports shall be outlined in the PSTP.

6.7.2 Inspection Reports

Any QA inspections that take place in the field or at the analytical laboratory while the verification testing is being conducted shall be formally reported by the FTO to the verification entity and manufacturer.

6.8 Corrective Action

Each PSTP must incorporate a corrective action plan. This plan must include the predetermined acceptance limits, the corrective action to be initiated whenever such acceptance criteria are not met, and the names of the individuals responsible for implementation.

Routine corrective action may result from common monitoring activities, such as:

- Routine site performance evaluation audits and
- Routine technical systems audits.

Content of PSTP Regarding QAPP:

The PSTP shall include the following elements:

- *Description of methodology for measurement of accuracy;*
- *Description of methodology for measurement of precision;*
- *Description of the methodology for use of blanks, the materials used, the frequency, the criteria for acceptable method blanks and the actions if criteria are not met;*
- *Description of any specific procedures appropriate to the analysis of the PE samples;*
- *Outline of the procedure for determining samples to be analyzed in duplicate, the frequency and approximate number;*
- *Description of the procedures used to assure that the data are correct;*
- *Listing of equations used for any necessary data quality indicator calculations. These include: representativeness, completeness, accuracy, precision, and statistical uncertainty.*
- *Outline of the frequency, format, and content of reports in the PSTP; and*
- *Development of a corrective action plan in the PSTP.*

The FTO shall be responsible for the following:

- Provision of all QC information such as calibrations, blanks and reference samples in an appendix. All raw analytical data shall also be reported in an appendix; and
- Provision of all data in hard copy and electronic form in a common spreadsheet or database format.

7.0 DATA MANAGEMENT AND ANALYSIS, AND REPORTING

7.1 Data Management and Analysis

A variety of data may be generated during a verification testing. Each piece of data or information identified for collection in the TSTP shall be provided in the report. The data management section of the PSTP shall describe what types of data and information needs to be collected and managed. It shall also describe how the data shall be reported to the NSF for evaluation.

Laboratory Analyses: The raw data and the validated data must be reported. These data shall be provided in hard copy and in electronic format. As with the data generated by the innovative equipment, the electronic copy of the laboratory data shall be provided in a spreadsheet in the report. In addition to the sample results, all QA/QC summary forms must be provided.

Other items that must be provided include:

- Field notebooks;
- Photographs, slides and videotapes (copies); and
- Results from the use of other field analytical methods.

7.2 Report of Equipment Testing

The FTO shall prepare a draft report describing the verification testing that was carried out and the results of that testing. This report shall include the following topics:

- Foreword;
- Introduction;
- Executive Summary;
- Description and Identification of Product Tested;
- Procedures and Methods Used in Testing;
- Results and Discussion (discussion of results should be kept at a minimum to a avoid conclusions and recommendations);
- References;
- Appendices;
- QA/QC Results; and
- Items described in section 7.1 of this document

Content of PSTP Regarding Data Management and Analysis, and Reporting:

The PSTP shall include the following:

- *Description of what types of data and information needs to be collected and managed and*
- *Description of how the data will be reported.*

8.0 SAFETY MEASURES

The FTO shall prepare a document identifying the safety procedures that shall be used during the field work. The safety procedures addressed in this document shallinclude the following as applicable:

- Storage, handling, and disposal of hazardous chemicals including acids, caustic and oxidizing agents;
- Conformance with electrical code;
- Biohazards, if pathogenic microorganisms are used in testing; and
- Ventilation of equipment or of trailers or buildings housing equipment, if gases generated by the equipment could present a safety hazard (one example is ozone).

Content of PSTP Regarding Safety:

The PSTP shall address safety considerations that are appropriate for the equipment being tested and for the challenge organisms, if any, being used in the verification testing.

APPENDIX 1A

STATE-SPECIFIC VERIFICATION TESTING REQUIREMENTS

Several states have indicated that they would require additional or modified verification testing tasks compared with those presented in this protocol and accompanying TSTPs. These additions or modifications are presented below as well as in any TSTP for which the states have requested altered tasks. If a manufacturer intends on installing their equipment in one of these states, it is recommended that they follow the requirements specified by the state rather than the minimum requirements of the protocol and TSTPs.

California:
The microbial testing sections in the TSTPs in this protocol should not be optional. It might be appropriate to list subsections of this section as optional, e.g., the *Giardia* and *Cryptosporidium* seeding experiments, but other testing, e.g., virus challenges, should be required or the technology should only be designated for use on watersheds in which there is no virus hazard.

CHAPTER 2

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN
FOR THE REMOVAL OF MICROBIOLOGICAL AND PARTICULATE CONTAMINANTS BY MEMBRANE FILTRATION

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1.0 APPLICATION OF THIS EQUIPMENT VERIFICATION TESTING PLAN

This document is the Environmental Technology Verification (ETV) Technology Specific Test Plan (TSTP) for evaluation of water treatment equipment for removal of microbiological and particulate contaminants using membrane filtration. This TSTP is to be used as a guide in the development of Product-Specific Test Plan (PSTP) procedures for testing membrane filtration equipment, within the structure provided by, "*Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Chapter 1, Requirements For All Studies*." This TSTP is only applicable to pressure-driven and vacuum-driven membrane processes. It does not apply to:

- Electrically-driven;
- Thermally-driven; or
- Concentration-driven membrane processes.

To participate in the equipment verification process for membrane filtration, the equipment manufacturer and its designated Field Testing Organization (FTO) shall employ the procedures and methods described in this TSTP and in the referenced ETV protocol document as guidelines for the development of the PSTP. The PSTP procedures should generally follow those tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written in the PSTP for each task should consist of the following sections:

- Introduction;
- Objectives;
- Work Plan;
- Analytical Schedule; and
- Evaluation Criteria.

Each PSTP shall include Tasks 1 to 8. Task 4, maximum pore size reporting and Task 9, raw water pretreatment, are not mandatory. For example, some manufacturers may wish to become verified for raw water pretreatment capabilities. In this case, the components of Task 9 should become a part of the PSTP.

2.0 INTRODUCTION

Pressure-driven membrane processes are currently in use for a broad number of water treatment applications ranging from removal of microbial contaminants such as *Giardia* and *Cryptosporidium*, to removal of natural organic matter contributing to disinfection by-product (DBP) formation. Typically, ultra low pressure membrane processes, such as microfiltration (MF) and ultrafiltration (UF) are employed to provide a physical barrier for removal of microbial and particulate contaminants from drinking waters. Higher pressure membrane applications such as nanofiltration (NF) and reverse osmosis (RO) are typically employed to achieve differing degrees of removal of total organic carbon (TOC), hardness ions, and other inorganic constituents such as salt species, in some applications. Nonetheless, this TSTP is applicable to any pressure-driven or vacuum-driven membrane process.

This TSTP is applicable to any membrane geometry as long as it is adequately described by the manufacturer. Various membrane geometries are currently employed for water treatment applications including:

- Spiral-wound (SW);
- Hollow-fiber (HF);
- Tubular;
- Cassette;
- Cartridge; and
- Flat sheet.

3.0 GENERAL APPROACH

This TSTP is broken down into nine tasks, as shown in the experimental matrix provided in Table 1. As noted above, Tasks 1 to 8 (except 4) shall be performed by any manufacturer wanting the performance of their equipment verified under the ETV Program. Tasks 4 and 9 are optional and can be implemented at the manufacturer's discretion. The manufacturer's designated FTO shall provide full detail of the procedures to be followed in each task in the PSTP. The FTO shall specify in the PSTP the operational conditions to be verified during the verification testing. All filtrate flux values shall be reported in terms of temperature-corrected flux values, as either gallons per square foot per day (gfd) at 68°F or liters per square meter per hour (L/(m^2-hr)) at 20ºC.

Table 1. Task Descriptions

Task	Testing Periods (minimum)	Issue	Test
Membrane Verification Testing Study			
1 Membrane flux and recovery	1	Rate of specific flux decline	Evaluate productivity at selected set of operational conditions.
2 Cleaning efficiency	1	Cleaning efficiency	Clean system to evaluate flux recovery.
3 Finished water quality	1	Finished water quality and rejection capabilities	Measure water quality & rejection capabilities.
4 Maximum pore size reporting	optional	Reporting of 90% and maximum pore size	Report 90% and maximum pore size for the membrane tested.
5 Membrane Integrity Testing	1	Integrity of membrane surface	Investigate integrity of membrane surface.
6 Data handling protocol			
7 QA/QC			
8 Microbial Removal	1	Removal of protozoa, bacteria, virus or surrogates	Conduct seeding experiments using MS2 virus, *Giardia*, *Cryptosporidium*, and/or surrogates if there is a relationship between the surrogate and the target microorganism that has been proven by peer-reviewed studies and proven methodologies.
9 Raw water pretreatment	optional	Pretreatment techniques that are not considered necessary	Demonstrate membrane performance after pretreatment and determine efficacy of pretreatment.

The total verification testing plan shall be performed over a one-month period (not including time for system set-up, shakedown and mobilization). At a minimum, one one-month period of verification testing shall be conducted to provide equipment testing information.

4.0 OVERVIEW OF TASKS

This section provides a brief overview of the required and optional tasks included in this TSTP.

4.1 Task A: Characterization of Feed Water

The objective of this initial operations task is to obtain a chemical, biological, and physical characterization of the feed water prior to testing.

4.2 Task B: Initial Test Runs

The objective of this initial operations task is to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water. This task is considered shakedown testing and shall be carried out prior to performing Tasks 1 through 8 (and Task 9, if applicable).

4.3 Task 1: Membrane Flux and Recovery

Task 1 will evaluate membrane operation and will entail quantification of membrane flux decline rates and product water recoveries. The rates of flux decline will be used to demonstrate membrane performance at the specific operating conditions to be verified. The specific operating conditions to be verified are the treatment conditions established during Task B initial test runs.

4.4 Task 2: Cleaning Efficiency

An important aspect of membrane operation is the restoration of membrane productivity after membrane flux decline has occurred. The objective of this task is to evaluate the efficiency of the membrane cleaning procedures recommended by the manufacturers. The fraction of specific flux that is restored following a chemical cleaning and after successive filter runs will be determined.

4.5 Task 3: Finished Water Quality

The objective of this task is to evaluate the quality of water produced by the membrane system. Multiple water quality parameters will be monitored during each test period. The mandatory water quality monitoring parameters shall include: turbidity, particle concentrations, total suspended solids (TSS), TOC, UV absorbance (at 254 nm wavelength), coliforms, and heterotrophic plate count (HPC) bacteria populations. Other water quality parameters will be optional, such as DBP formation potential. A basic goal of this task is to confirm that membrane treated waters meet manufacturer's stated performance capabilities. Water quality produced will be evaluated in relation to feed water quality and operational conditions.

4.6 Task 4: Reporting of Membrane Pore Size (Optional)

Membranes for particle and microbial removal do not have a single pore size, but rather have a distribution of pore sizes. For example, a nominally rated 0.1 μm MF membrane may have pores ranging from 0.08 μm to 0.4 μm. Membrane rejection capabilities are thus limited by the maximum membrane pore size. The objective of this task is to report the 90% and maximum membrane pore size of the membranes employed in field operations. This is a suggested task.

4.7 Task 5: Membrane Module Integrity

A critical aspect of any membrane process is the ability to verify that a membrane process is producing a specified water quality on a continual basis. For example, it is important to know whether the membrane is providing a constant barrier to protozoan oocysts such as *Cryptosporidium*. The objective of this task is to demonstrate the methodology to be employed for monitoring membrane integrity and to verify the integrity of membrane modules.

4.8 Task 6: Data Handling Protocol

The objective of this task is to establish an effective field protocol for data management at the field operations site and for data transmission between the FTO and NSF International (NSF).

4.9 Task 7: Quality Assurance and Quality Control

An important aspect of verification testing is the protocol developed for quality assurance and quality control (QA/QC). The objective of this task is to assure accurate measurement of operational and water quality parameters during membrane equipment verification testing.

4.10 Task 8: Microbial Removal

The objective of this task is to evaluate microbial removal capabilities by seeding the systems with target organisms which shall include, but are not limited to, selected protozoa and viruses. The manufacturer shall choose to have either a field microbial seeding study or bench-scale microbial testing performed as part of their verification testing. The introduction of surrogates for protozoa and viruses may be allowed only when peer-reviewed studies and proven methodologies have shown the relationship between surrogates and target microorganisms.

4.11 Task 9: Raw Water Pretreatment (Optional)

Most membrane processes that are employed for particle and microbial removal require no pretreatment, except for pre-screening, and therefore require no optional pretreatment testing per the requirements of this TSTP. Furthermore, in cases where a pretreatment technique is considered an integral part or inseparable part of the function of the membrane system, no additional testing of system pretreatment capabilities would be necessary. However, some manufacturers may wish to employ an optional pretreatment technique that does not represent an integral part of the membrane technology for removal of microbiological and particulate contaminants. Such optional pretreatment may be employed to extend membrane operational time or remove selected contaminants.

The objective of this raw water pretreatment task is to evaluate the efficacy of raw water pretreatment for improvement of membrane operation or removal of selected contaminants. The specific goals of this task will be to evaluate raw water pretreatment required prior to membrane filtration and to evaluate any changes in treated water quality associated with raw water pretreatment.

5.0 TESTING PERIODS

The required tasks of the TSTP (Tasks 1 through 8, except Task 4) are designed to be completed over a minimum of one verification testing period of one month (30 days), not including mobilization, shakedown and start-up. Membrane testing conducted beyond the testing period may be used for fine-tuning of membrane performance or for evaluation of additional operational conditions. Many of the tasks presented as Tasks 2 through 7 can be performed concurrent with Task 1, the flux and operational testing procedures. Task 8 may also be conducted during the testing period if a field study is chosen or before, during or after the testing period, if a bench-scale laboratory test is chosen. However, Task 9 shall be performed in an additional month of testing.

Additional verification testing periods may be necessary to verify the manufacturer's statement of performance capabilities, such as in the treatment of surface water where additional testing during each season may assist in verifying a statement of performance capability. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's statement of performance capabilities. For example, a good challenge for a membrane would be a test period during which the feed water exhibits low temperature, high turbidity and/or natural organic matter. Although one test period satisfies the minimum requirement of this TSTP, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined in initial operations. Performance and reliability of the equipment shall be tested during verification testing periods at a minimum of 30 days. The purpose of the one month test period is to demonstrate the ability of the equipment to meet the water quality goals specified by the manufacturer, the product water recovery, and the rate of flux decline observed over the one month period of operation.

6.0 DEFINITION OF OPERATIONAL PARAMETERS

Definitions that may apply to membrane filtration include:

6.1 Filtrate: Water produced by the membrane filtration process.

6.2 Feed Water: Water introduced to the membrane module.

6.3 Filtrate Flux: The average filtrate flux is the flow of product water divided by the surface area of the membrane. It should be noted that gfd and L/(m2-hr) shall only be used as units of flux. Filtrate flux is calculated according to the following formula:

$$J_t = \frac{Q_p}{S}$$

where J_t = filtrate flux at time t (gfd, L/(m2-hr);
Q_p = filtrate flow (gpd, L/h); and
S = membrane surface area (ft^2, m^2).

6.4 Specific Flux: The term specific flux is used to refer to filtrate flux that has been normalized for the transmembrane pressure. The equation used for calculation of specific flux is given as follows:

$$J_{tm} = \frac{J_t}{NDP}$$

where J_{tm} = specific flux at time t (gfd/psi, L/(m2-hr)/bar);
J_t = filtrate flux at time t (gfd, L/(m2-hr)); and
P_{tm} = transmembrane pressure (psi, bar).

Specific flux results shall always be reported with indication of the time interval after initiation of the experimental test run.

6.5 Membrane Fouling: A reduction in filtrate flux that can be restored by mechanical or chemical means is termed "reversible" fouling. In contrast, "irreversible fouling" is defined as a permanent loss in filtrate flux capacity that cannot be restored. The fouling of membranes designed for particle or microbial removal is primarily attributed to deposition of materials on the membrane surface and/or in the membrane pores.

6.6 Transmembrane Pressure: The average transmembrane pressure is calculated:

$$P_{tm} = \left[\frac{(P_i + P_o)}{2} - P_p \right]$$

where P_{tm} = transmembrane pressure (psi, bar);
P_i = pressure at the inlet of the membrane module (psi, bar);
P_o = pressure at the outlet of the membrane module (psi, bar); and
P_p = filtrate pressure (psi, bar).

6.7 Temperature Adjustment for Flux Calculation: Temperature corrections to 20°C for transmembrane flux shall be made to correct for the variation of water viscosity with temperature. A specific, empirically derived equation developed by the membrane manufacturer may be used to provide temperature corrections. Alternatively, the following equation by Streeter and Wiley (1985) may be employed:

$$J_t \text{ (at } 20^\circ \text{ C)} = \frac{Q_p \times e^{-0.0239 \cdot (T-20)}}{S}$$

where J_t = instantaneous flux (gfd, L/(m2-hr));
Q_p = filtrate flow (gpd, L/h);
T = temperature, (°F, °C); and
S = membrane surface area (ft^2, m^2).

6.8 Feed Water System Recovery: The recovery of filtrate from feed water is given as the ratio of filtrate flow to feed water flow:

$$\%\,\text{System Recovery} = 100 \cdot \left[\frac{Q_p}{Q_f} \right]$$

where Q_p = filtrate flow (gpd, L/h) and
Q_f = feed flow to the membrane (gpd, L/h).

6.9 Membrane Element Recovery: The recovery of filtrate from total recirculation influent water is given as the ratio of filtrate flow to the sum of feed water flow and recycle flow:

$$\%\,\text{Element Recovery} = 100 \left[\frac{Q_p}{Q_f + Q_r} \right]$$

where Q_p = filtrate flow (gpd, L/h);
Q_f = feed flow to the membrane (gpd, L/h); and
Q_r = recycle flow (gpd, L/h).

7.0 TASK A: CHARACTERIZATION OF FEED WATER

This initial operations task is needed to determine if the chemical, biological, and physical characteristics of the feed water are appropriate for the water treatment equipment to be tested.

7.1 Objectives

The objective of this task is to obtain a complete chemical, biological, and physical characterization of the feed water that will be entering the treatment system being tested.

7.2 Work Plan

This task can be accomplished by using analytical measurements obtained from third party sources (i.e. USGS, EPA, state laboratories, municipal laboratories). The specific parameters needed to characterize the water will depend on the equipment being tested but information on the following characteristics should be compiled:

- Temperature, pH, turbidity, and UV_{254} absorbance;
- Total alkalinity and total hardness;
- TOC, Total Dissolved Solids (TDS), and TSS; and
- Total coliform (TC) and HPC bacteria.

If sufficient historic data is not available to properly evaluate the feed water quality, additional monitoring of the feed water should be performed to adequately assess feed water quality. Ideally, one year of historic water quality data for each parameter will be available for the proposed feed water. At a minimum, one month of data, sampled at no greater than weekly intervals, may constitute historic data.

Sufficient information shall be obtained to illustrate the variations expected to occur in these parameters that will be measured during verification testing for the water source. This information shall be compiled and shared with NSF, so NSF and the FTO can determine the adequacy of the data for use as the basis to make decisions on the testing schedule. Failure to adequately characterize the feed water could result in testing at a site later deemed inappropriate, so the initial characterization will be important to the success of the testing program.

7.3 Analytical Schedule

In many cases, sufficient water quality data may already exist to permit making a determination of the suitability of a source water for use as feed water in a membrane verification testing program. If sufficient historic data is not available to properly evaluate the source water quality, additional monitoring of the source water shall be performed to adequately assess source water quality.

7.4 Evaluation Criteria

Feed water quality will be evaluated in the context of the manufacturer's statement of performance capabilities. The feed water should challenge the capabilities of the equipment but should not be beyond the range of water quality suitable for treatment for the equipment in question.

8.0 TASK B: INITIAL TEST RUNS

8.1 Objectives

The objective of initial test runs, also called shakedown testing, is to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water.

8.2 Work Plan

Initial test runs shall be conducted so a preliminary assessment of treatment performance can be made. If more than one verification test period is planned, this task shall occur prior to each test period. This task is considered shakedown testing and shall be carried out prior to performing Tasks 1 through 9 (Tasks 4 and 9 are optional).

8.3 Analytical Schedule

Because these runs are being conducted to determine the suitability of the technology for verification testing, a strictly defined schedule for sampling and analysis does not need to be followed. Adhering to the schedule for sampling and analysis to be followed during verification testing would be wise so the operator can gain familiarity with the time requirements that will be applicable later on in the test program.

8.5 Evaluation Criteria

The manufacturer and FTO shall evaluate the data produced during the initial test runs to determine if the water treatment equipment performance met or exceeded expectations based on the statement of performance capabilities. If the performance was not as good as the statement of performance capabilities, the manufacturer may wish to conduct more initial test runs or to cancel the testing program.

9.0 TASK 1: MEMBRANE FLUX AND OPERATION

9.1 Introduction

Membrane operation will be evaluated in this task, with quantification of membrane flux decline rates and product water recoveries. The rates of flux decline will be used to demonstrate membrane performance at the specific operating conditions to be verified. The operational conditions to be verified shall be specified by the manufacturer and described by the FTO in the PSTP in terms of a temperature-corrected flux value (e.g., gfd at 68°F or L/(m^2-hr) at 20°C) before the initiation of the verification test.

The rate of specific flux decline is a function of water quality and operational conditions. In this task, water quality shall be monitored and operational conditions varied depending upon membrane flux decline profiles. Flow and pressure data shall be collected to quantify the loss of productivity in terms of rate of specific flux decline. A lower rate of specific flux decline implies that a longer operational run will be achieved by the membrane system.

9.2 Experimental Objectives

The objectives of this task are to demonstrate: 1) the appropriate operational conditions for the membrane equipment; 2) the product water recovery achieved by the membrane equipment; and 3) the rate of flux decline observed over extended membrane filtration operation. Raw water quality shall be monitored (Task 3) during each seasonal one-month testing period at a minimum, to track any significant variations that could impact rates of membrane flux decline.

It should be noted that the objective of this task is not process optimization, but rather verification of membrane operation at the operating conditions specified by the manufacturer and described by the FTO in the PSTP, as pertains to filtrate flux and transmembrane pressure.

9.3 Work Plan

Determination of optimal membrane operating conditions for a particular water can typically require as long as one year of operation. For this task, the manufacturer shall specify the operating conditions and shall supply written procedures on the operation and maintenance (O&M) of the membrane treatment system. The manufacturer shall also specify the termination criteria for their particular membrane equipment. For example, the termination criteria may consist of an 80% decline in specific flux, or increase in transmembrane pressure to a specific value. In this task, each set of operating conditions shall be maintained for the one month testing period (continuous 24-hour operation). The manufacturer shall specify the primary filtrate flux at which the equipment is to be

verified. The FTO shall describe the operating conditions and include a copy of the manufacturer's O&M manual in the PSTP.

After set-up and shakedown of membrane equipment, membrane operation should be established at the flux condition to be verified. The membrane system shall be operated as shown schematically in Figure 1 for a minimum of one month. If substantial specific flux decline of the membrane occurs at the specified flux before the one month operating period is complete, chemical cleaning shall be performed and adjustments to the operational strategy shall be made (such as a decrease in transmembrane flux or an increase in backwash frequency, if applicable). The manufacturer shall make decisions on adjustments to the operational strategy. At a minimum, the membrane shall be chemically cleaned according to the manufacturer specifications at the conclusion of the one month period. At this time, the cleaning efficiency will be determined per Task 2.

This membrane TSTP has been written with the aim to balance the costs of verification with the benefits of testing membrane filtration over a wide range of operating conditions. Given that it may take as long as a month and longer to observe significant flux decline in a membrane system, examination under a wide range of operating conditions would be prohibitively expensive for the membrane manufacturer. Therefore, this TSTP requires that one set of operating conditions be tested for a one-month testing period. It shall be furthermore understood that beyond the single set of verification operating conditions, membrane operation that occurs at a lower flux, a lower recovery, or a higher cross-flow velocity shall also constitute a verifiable condition.

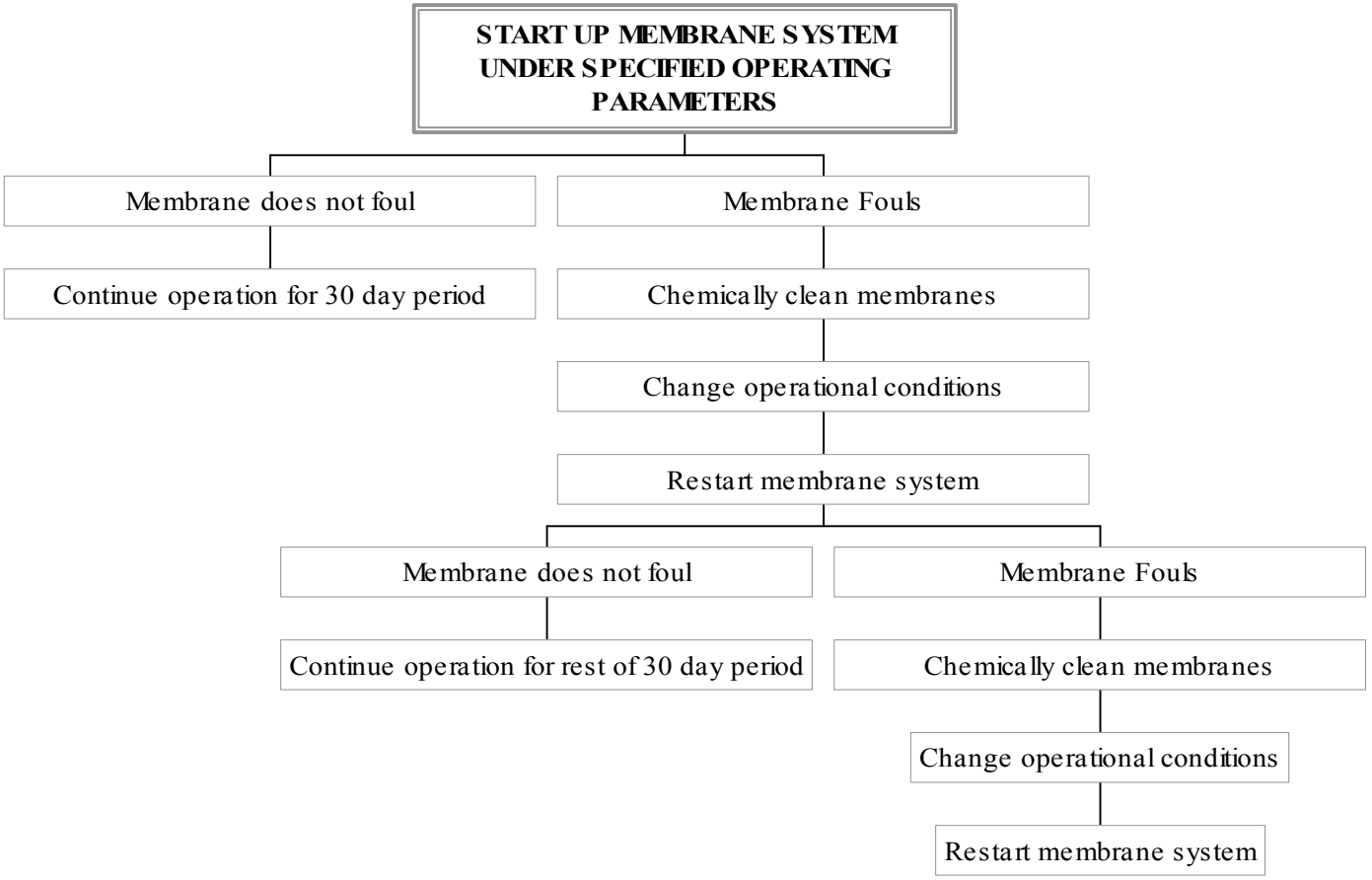
To establish appropriate conditions of flux, recovery, backwash frequency and duration, the manufacturer may have some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to perform shakedown tests as described in Task B so that reasonable operating criteria can be established. This would aid in preventing the unintentional but unavoidable optimization during the verification testing.

Testing of additional operational conditions may be included in the verification testing program at the discretion of the manufacturer and its designated FTO. However, testing of alternate additional operational conditions shall be performed by including additional one-month testing periods beyond the one month required by the TSTP.

Additional months of testing may also be included in the PSTP to demonstrate membrane performance under different feed water quality conditions. For membrane filtration, extremes of feed water quality (e.g., low temperature, high turbidity) are the conditions under which membranes are most prone to rapid flux decline and to failure. The FTO shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional one-month testing period, as required above for each additional set of operating conditions.

The testing runs conducted under this task shall be performed in conjunction with Tasks 2, 3, 5, 8 (if a field seeding study is conducted) and the optional Task 9. With the exception of the additional testing periods conducted at the manufacturer and FTO's discretion, no additional membrane test runs are required for performance of Tasks 2, 3, 5, 8 or 9.

Figure 1
Schematic of Membrane Operational Plan



9.4 Analytical Schedule

9.4.1 Operational Data Collection

Measurement of membrane feed water flow and filtrate flow (recycle flow where applicable), system pressures and feed water temperature shall be collected at a minimum of two times per day. Table 2 presents the operational data collection schedule. Measurement of feed water temperature to the membrane shall be made daily to provide data for correction of transmembrane flux.

Table 2. Operational Data Collection Schedule

Location		Minimum Frequency
Raw		
	Flow	2/day
	Feed water Temperature	1/day
Single Stage Membrane Processes		
	Influent module/vessel pressure	2/day
	Effluent module/vessel pressure	2/day
	Filtrate pressure	2/day
	Filtrate flow	2/day
Multiple Stage Membrane Processes		
	Stage 1 Influent module pressure	2/day
	Stage 1 Effluent module pressure	2/day
	Stage 1 Feed flow	2/day
	Stage 1 Filtrate pressure	2/day
	Stage 1 Filtrate flow	2/day
	Stage 2 Influent module pressure	2/day
	Stage 2 Effluent module pressure	2/day
	Stage 2 Feed flow	2/day
	Stage 2 Effluent module flow	2/day
	Stage 2 Filtrate pressure	2/day
	Stage 2 Filtrate flow	2/day
	Crossflow velocity	2/day

Note: The FTO should adapt the operational data collection location to the particular geometry of the membrane system.

In an attempt to calculate cost factors for small-scale operation of membrane equipment, power usage for operation of the membrane equipment shall also be closely monitored and recorded by the FTO during each testing period. Power usage shall be estimated by inclusion of the following details regarding equipment operation requirements: (pumping requirements, size of pumps, nameplate voltage, current draw, power factor, chemical usage, etc.). In addition, measurement of power consumed shall be provided by information on current draw and power consumption. Chemical usage shall be quantified by recording day tank concentration and daily volume consumption. No additional operational data shall be required by Tasks 2 and 3 unless specifically stated.

9.4.2 Feed Water Quality Limitations

The characteristics of feed waters used during the testing period (and any additional one-month testing periods) shall be explicitly stated in reporting the membrane flux and recovery data for each season. Accurate reporting of such feed water characteristics as temperature, turbidity, and TSS is critical, as these parameters may substantially influence the range of achievable membrane performance on a seasonal basis. In addition, accurate reporting of water quality characteristics such as pH, alkalinity, and TOC shall be reported on a monthly basis to provide a general background on the source water character and quality for each testing period. More frequent monitoring of these parameters may be performed if desired by the manufacturer or recommended by FTO.

9.5 Evaluation Criteria and Minimum Reporting Requirements

- Transmembrane pressure (P_{tm}) :
  - Plot graph of transmembrane pressure over time for each 30 day period of operation.
- Rate of specific flux decline:
  - Plot graph of specific flux normalized to 20°C over time for each 30 day period of operation.
- Cleaning efficiency:
  - Provide table of intervals between chemical cleaning episodes and efficiency of cleaning achieved following each 30 day period of operation.

10.0 TASK 2: CLEANING EFFICIENCY

10.1 Introduction

Following the test runs of Task 1, the membrane equipment may require chemical cleaning to restore membrane productivity. The number of cleaning efficiency evaluations shall be determined by the rate of specific flux decline of the membrane during the test period. At a minimum, one cleaning shall be performed at the conclusion of the required testing. In the case where the membrane does not fully reach the operational criteria for termination as specified by the manufacturer and its designated FTO in Task 1, chemical cleaning shall be performed after the 30 days of operation, with a record made of the operational conditions before and after cleaning.

10.2 Experimental Objectives

The objective of this task is to evaluate the effectiveness of chemical cleaning for restoring finished water productivity to the membrane systems. The intent of this task is to confirm that standard manufacturer-recommended cleaning practices are sufficient to restore membrane productivity for the systems under consideration. Cleaning chemicals and cleaning routines shall be based on the recommendations of the manufacturer; this task is considered a "proof of concept" effort, not an optimization effort. It should be noted that cleaning solution selection is typically feed water quality specific. The PSTP procedures should permit evaluation of cleaning solutions that are considered optimal for water being treated. If the manufacturer determines that a pre-selected cleaning formulation is not effective, the PSTP procedures should allow the manufacturer to modify it.

10.3 Work Plan

The membrane systems may experience substantial specific flux decline during the membrane test runs conducted for Task 1. At the conclusion of the test period, membranes shall be utilized for the cleaning assessments herein. No additional experiments shall be required to produce specific flux decline such that chemical cleaning evaluations be performed. Each system shall be chemically cleaned using the recommended cleaning solutions and procedures specified by the manufacturer. After each chemical cleaning of the membranes, the system shall be restarted and the initial conditions of specific flux recovery and rejection capabilities shall be tested.

The manufacturer and its designated FTO shall specify in detail the procedure(s) for chemical cleaning of the membranes in the PSTP. At a minimum, the following shall be specified:

- Cleaning chemicals;
- Quantities cleaning chemicals;
- Hydraulic conditions of cleaning;
- Duration of each cleaning step;
- Initial and final temperatures of chemical cleaning solution; and
- Quantity and characteristics of residual waste volume to be disposed.

In addition, detailed procedures describing the methods for pH neutralization of the acid or alkaline cleaning solutions should be provided along with information on the proper disposal method for regulated chemicals. A description of all cleaning equipment and its operation shall be included in the PSTP.

10.4 Analytical Schedule

10.4.1 Sampling

The pH, turbidity and TDS of each cleaning solution shall be determined and recorded during various periods of the chemical cleaning procedure. In addition, in the case that the cleaning solution employs an oxidant, such as chlorine, the concentration of the oxidant both before and at the end of the cleaning should be measured. Notes recording the visual observations (color, degree of suspended matter present) shall also be provided by the FTO. No other water quality sampling shall be required.

10.4.2 Operational Data Collection

Flow, pressure, and temperature data shall be collected during the cleaning procedure if possible and shall be recorded immediately preceding system shutdown due to substantial membrane flux decline; flow, pressure, and temperature data shall also be collected immediately upon return to membrane operation, after chemical cleaning.

10.5 Evaluation Criteria and Minimum Reporting Requirements

At the conclusion of each chemical cleaning event and upon return to membrane operation, the initial condition of transmembrane pressure, recovery and temperature shall be recorded and the specific flux calculated. The efficacy of chemical cleaning shall be evaluated by the recovery of specific flux after chemical cleaning as noted below, with comparison drawn from the cleaning efficacy achieved during previous cleaning evaluations. Comparison between chemical cleanings shall allow evaluation of the potential for irreversible loss of specific flux and projections for usable membrane life.

Two primary indicators of cleaning efficiency and restoration of membrane productivity will be examined in this task:

1) The immediate recovery of membrane productivity, as expressed by the ratio between the final specific flux value of the current filtration run (Js_f) and the initial specific flux (Js_i) measured for the subsequent filtration run:

$$\% \text{ Recovery of Specific Flux} = 100\left[1 - \frac{Js_f}{Js_i}\right]$$

where: Js_f = Specific flux (gfd/psi, L/(m2-hr)/bar) at end of current run (final) and
Js_i = Specific flux (gfd/psi, L/(m2-hr)/bar) at beginning of subsequent run (initial).

2) The loss of specific flux capabilities, as expressed by the ratio between the initial specific flux for any given filtration run (Js_i) divided by the specific flux (Js_{io}) at time zero, as measured at the initiation of the first filtration run in a series:

$$\text{Loss of Original Specific Flux} = 100\left[1 - \frac{Js_i}{Js_{io}}\right]$$

where: Js_{io} = Specific flux (gfd/psi, L/(m2-hr)/bar) at time zero point of membrane testing.

The minimum reporting requirements shall include presentation of the following results:

- Flux recovery:
  - Provide table of post cleaning flux recoveries during each 30 day period of operation.
- Cleaning efficacy:
  - Provide table of cleaning efficacy indicators described above for chemical cleaning procedures performed during each 30 day period of operation.
- Assessment of irreversible loss of specific flux and estimation of usable membrane life for costing purposes.

11.0 TASK 3: FINISHED WATER QUALITY

11.1 Introduction

Water quality data shall be collected for the feed water and membrane filtrate water as shown in the sampling schedule Table 3, during the membrane test runs of Task 1. At a minimum, the required sampling schedule shown in Table 3 shall be observed by the FTO. Water quality goals and target removal goals for the membrane equipment shall be recorded in the PSTP.

11.2 Experimental Objectives

The objective of this task is to assess the ability of the membrane equipment to meet the water quality goals specified by the manufacturer. A list of the minimum number of water quality parameters to be monitored during equipment verification testing is provided in the analytical schedule section below and in Table 3. The actual water quality parameters selected for testing shall be stipulated by the FTO in the PSTP.

11.3 Work Plan

Many of the water quality parameters described in this task shall be measured on-site by the FTO (refer to Table 4). Analysis of the remaining water quality parameters shall be performed by a laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the EPA. The methods to be used for measurement of water quality parameters in the field are described in the analytical methods section below and in Table 4. The analytical methods utilized in this study for on-site monitoring of feed water and filtrate water qualities are described in Task 7, QA/QC. Where appropriate, the *Standard Methods* reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at a laboratory, water samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the laboratory.

11.4 Analytical Schedule

11.4.1 Feed and Filtrate Water Characterization

At the beginning of the testing period at a single set of operating conditions (and thereafter with indicated frequency), the raw water and filtrate water shall be characterized by measurement of the following water quality parameters (as indicated in Table 3):

- Alkalinity and Hardness (both monthly);
- TSS and TDS (both once every two weeks);
- TOC and $UV_{254\ nm}$ absorbance (both monthly);
- TC and HPC bacteria (once per week);
- Temperature (daily, feed only);
- pH (twice per week);
- Filtrate water turbidity and particle concentrations (twice daily); and
- Feed (and concentrate) water turbidity and particle concentrations (twice daily).

Table 3. Water Quality Sample Schedule									
		Single Stage Process			Multiple Stage Processes				
					Stage 1			Stage 2	
Parameter	Sampling Frequency	Feed	Filtrate	Back-wash Waste	Feed	Filtrate	Concen-trate	Filtrate	Backwash Waste
On-Site Analytes									
pH	Twice/week	1	0	0	1	1	1	1	1
Temperature	Daily	1	0	0	1	0	0	0	0
Turbidity	Daily	2	C[1]	2	2	C[1]	2	C[1]	2
Particle counts	Daily	2	C[1]	0	2	C[1]	1	C[1]	1
Laboratory Analysis									
Alkalinity	Monthly	1	1	0	1	1	1	1	1
Total/calcium hardness	Monthly	1	1	0	1	1	1	1	1
TDS	Once/2 weeks	1	1	0	1	1	1	1	1
TSS	Once/2 weeks	1	1	1	1	1	1	1	1
TC	Weekly	1	1	1	1	1	1	1	1
HPC	Weekly	1	1	0	1	1	1	1	1
TOC	Monthly*	1	1	0	1	1	1	1	1
UVA	Monthly*	1	1	0	1	1	1	1	1
DBP Formation Potential Analysis(Optional)									
Total THMs	Monthly	1	1	0	1	1	0	1	0
HAA6	Monthly	1	1	0	1	1	0	1	0

C[1] continuous monitoring * more frequent monitoring may be performed at the discretion of the manufacturer or FTO.

Table 4. Analytical Methods			
Parameter	Facility	*Standard Methods*[1] number or Other Method Reference	EPA Method[2]
General Water Quality			
Temperature	On-Site	2550 B	
pH	On-Site	4500-H^+ B	150.1 / 150.2
Total alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Calcium Hardness	Lab	3500-Ca D	
TSS	Lab	2540 D	
TDS	Lab	2540 C	
Particle Characterization			
Turbidity Bench top	On-Site	2130 B / Method 2	180.1
Turbidity In Line	On-Site	Manufacturer	
Particle Counts Bench top	On-Site	Manufacturer	
Particle Counts In Line	On-Site	Manufacturer	
Organic Compound Characterization			
TOC/DOC	Lab	5310B/5310C	
UV_{254} absorbance	Lab	5910 B	
Total THMs	Lab		524.2; 502.2
HAA6	Lab	6251B	552.1
Microbiological			
TC and HPC	Lab	9221 / 9222 / 9223 /9215 B	
Cryptosporidium	Lab	NSF and EPA may consider alternative methods if sufficient data on precision, accuracy, and comparative studies are available for alternative methods.	EPA 1622, EPA 1623
MS2 virus	Lab		EPA ICR Method for Coliphage Assay, 1996

Notes: 1) *Standard Methods* Source: 20th Edition of Standard Methods for the Examination of Water and Wastewater, 1999, American Water Works Association.

2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

11.4.2 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during the period of membrane testing, as required in Table 3. For verification of particulate removal, turbidity and particle concentrations in filtrate waters shall be monitored continuously using either batch or in-line analytical instruments. Grab samples of feed waters to the membrane system shall be measured by the FTO twice daily for turbidity and particle concentrations using bench-top analytical equipment. The specific particle size ranges to be monitored by both in-line and bench-top analytical equipment during the verification testing are indicated in Task 7, the QA/QC section.

Water quality parameters including pH and temperature shall be monitored daily. TSS shall be monitored every other week and results of this analysis will be used to construct a mass balance of suspended solids through the membrane system. Monitoring of organic water quality parameters such as TOC and UV_{254} absorbance shall be performed on a monthly basis to evaluate rejection of organics by the membrane. Additional sampling and data collection may be performed at the discretion of the FTO.

In the case of water quality samples to be shipped to the laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the U.S. EPA for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the laboratory. These samples shall be preserved, stored, shipped, and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory. All PSTPs shall include, at a minimum, a table(s) showing the parameters to be analyzed, analytical method, the laboratory reporting limit or quantitation limit, sample volume, bottle type, preservation method, and holding time.

On a weekly basis, samples of raw and filtrate waters shall be collected for analysis of indigenous bacterial densities including: TC and HPC. Collected samples shall be placed in a cooler with blue ice to be shipped with an internal cooler temperature of approximately 2-8°C to a laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the EPA. Samples shall be processed for analysis by the laboratory within 24 hours of collection. The laboratory shall then keep the samples at a temperature of approximately 2-8°C until initiation of analysis. TC densities will be reported as most probable number per 100 mL (MPN/100 mL) and HPC densities will be reported as colony forming units per milliliter (cfu/mL).

11.4.3 Feed Water Quality Limitations

The characteristics of feed waters encountered during the testing period shall be explicitly stated in reporting the membrane flux and recovery data. Accurate reporting of such feed water characteristics as temperature, turbidity, TSS, pH, alkalinity and hardness is critical for the verification testing program, as these parameters can substantially influence membrane performance on a seasonal basis.

11.4.4 Turbidity Spiking (Optional Task)

If the anticipated turbidity at the selected site does not challenge the system to the limits of its performance capabilities, an optional turbidity augmentation procedure may be implemented after the 30 days of verification testing has been completed. A procedure for turbidity spiking was published in *Journal American Water Works Association* (AWWA) in December 1993, pp. 39-46 by Logsdon et al. A spiking procedure based on the published technique is described in the following paragraphs. (In this ETV document, when the word "tank" is used, this term includes a storage tank, an above-ground swimming pool of appropriate size, an earthen basin having a plastic liner, or any other device or means of holding large volumes of water.)

To spike turbidity, use of a local turbidity source is recommended. This could consist of sediments taken from the bottom of a river or lake, or natural soil of the type likely to erode into nearby watercourses and cause turbid waters. For testing done in many locations in the United States where row crop agriculture is practiced, topsoil could be used to prepare a suspension for turbidity spiking, because topsoil is a major contributor to turbid runoff as a result of heavy rains in such locations. Topsoil or sediments would be expected to contain some natural organic matter, and as such would enable the FTO to produce a turbidity suspension typical for much of the turbid runoff found in the United States.

The soil or sediments that will be used to prepare a suspension for turbidity spiking should be screened through a three inch screen to remove rocks, for protection of pumps that will be used to mix soil and water.

After screening, soil or sediment should be added in a batch tank having a capacity in the range of 400 to 1000 gallons. Mixing can be accomplished by using a pump with a flow capacity, expressed in gallons per minute, of about 10% of the batch tank volume, expressed in gallons. For a 400 gallon batch tank, a 40 gpm pump theoretically could pump one tank volume in ten minutes. Use of a trash pump or dewatering pump capable of pumping very muddy water or suspensions of water and mud is recommended. The mixture of water and soil or sediment should be recirculated for about six to eight hours. The action of the pump impeller will help to break up soil particles to smaller sizes that do not settle rapidly.

After the turbidity slurry has been mixed as described above and then settled for one hour to allow small gravel, sand, and grit to settle to the bottom of the batch tank, the slurry can be transferred to a very large tank having the capacity in the range of 10,000 to 15,000 gallons. The diluted suspension should be stirred or recirculated using a gasoline-powered portable pump of the kind used for dewatering at project construction sites, or an electric powered pump of equivalent flow capacity. The objective is to mix the water and slurry with a turnover time of about one hour. This mixing should be done for about six to eight hours, followed by two hours of quiescent settling for removal of the larger particles that would settle of their own accord during treatment. After settling, the turbidity suspension can be blended into feed water to make a more turbid feed water, or depending on the size of the treatment equipment being evaluated, and the length of the filter run, the turbidity suspension in the large tank might be used directly as feed water. If the turbidity suspension was to be used directly, more uniform turbidity could be attained by transferring the suspension to a second large tank that could be continuously stirred.

Depending on the number and duration of filter runs for which highly turbid water will be needed, sequential use of two large tanks may be appropriate. In such a situation, one large tank would be used for stirring and settling the turbidity slurry, while the second large tank would be used as the source of turbid water for spiking or as the source of feed water.

As an alternative to the use of the 10,000 to 15,000 gallon tanks described above, a second tank in the size range of 400 to 1000 gallons could be used. In this case, the suspension that had been mixed in the first 400 to 1000 gallon tank would be settled for two hours in the original tank, and about 80% of the contents would be decanted from the first tank to the second tank, leaving the sediments on the bottom undisturbed. The second tank should be stirred to maintain the turbidity-causing particles in suspension. The suspension that has been transferred to the second tank could be fed as a concentrated suspension and thoroughly mixed into the source water to create the turbid feed water. In this approach to turbidity spiking, an in-line mixer should be used to ensure effective mixing of the turbidity suspension and the source water. Sampling of feed water for turbidity analysis should be done only after the spiked turbidity suspension is thoroughly mixed into the feed water. After the turbidity suspension has been transferred to the second tank where the suspension can be used for spiking, preparation of another batch of turbidity suspension could begin again in the first tank.

The size of the tanks and the amount of soil or sediment slurry originally prepared in the highly concentrated form in the first mixing tank (the 400 to 1000 gallon tank described above) may be influenced by the rate of flow of the treatment equipment being tested, and by the level of turbidity the FTO is trying to attain. Use of treatment equipment with larger flows, and selection of high turbidity goals may result in the need for bigger tanks and pumps and the use of considerably more soil, silt, or sediment. An estimate of the amount of soil could be made by estimating the mass concentration of suspended solids needed to produce a desired turbidity. In making such an estimate, though, the FTO should consider that a substantial portion of the soil might not be broken up into particles so fine that they do not settle out in the recommended settling times. Therefore, soil usage estimates based on suspended solids would understate actual soil requirements.

The turbid water fed in the treatment testing could be characterized by particle counting, in addition to turbidity measurement. In many cases this would require dilution of the turbid samples. A simpler test would be to collect a sample of the water and place it in a 1000 mL graduated cylinder, and then record the location of the interface between turbid water and clearer water over a period of three to five hours as the suspension settles. A turbidity suspension that settled very slowly would be representative of turbid water containing fine particulate matter that would be found in many surface waters after heavy runoff.

11.4.5 Removal of Simulated Distribution System DBP Precursors (Optional Task)

During the steady-state operation of the testing period, optional simulated distribution system (SDS) DBP testing will be performed on the membrane feed water and the filtrate product water to determine the precursor removal capabilities of the membrane system. SDS DBP testing will be used to estimate by-product formation (primarily trihalomethanes and haloacetic acids). This SDS method shall be performed by spiking a water sample with a disinfectant and holding the sample in the dark at the uniform formation conditions (UFC) specified in the Information Collection Rule (ICR) Manual for Bench- and Pilot-Scale

Treatment Studies. Alternatively, the conditions selected for SDS evaluation may be those that most closely approximate the detention time and chlorine residual found in the distribution system at the location of verification testing. (Refer to the SDS test protocol in the QA/QC section of this TSTP for further details.) The following UFC will be used for DBP formation testing:

- Incubation period of 24 +/- 1 hour;
- Incubation temperature of 20 +/- 1.0°C;
- Buffered pH of 8.0 +/- 0.2; and
- 24-hour chlorine residual of 1.0 +/- 0.4 mg Cl_2/L.

11.5 Evaluation Criteria and Minimum Reporting Requirements

- Turbidity, particle concentrations and particle removal:
  - Plot graph of feed and filtrate turbidity at four hour intervals over time during each 30 day period of operation;
  - Plot graph of feed and filtrate particle concentrations at four hour intervals over time during each 30 day period of operation;
  - Plot graph of log removal of particles between feed water and filtrate water at one-day intervals over time during each 30 day period of operation; and
  - Perform mass balance calculations of TSS through the membrane system and calculate concentrations of TSS in the backwash wastewater. Calculated values shall be compared with actual measured TSS concentrations in backwash waste. (These backwash TSS concentrations may be an important consideration for residuals disposal.).
- Water quality and removal goals specified in the PSTP:
  - Provide feed and filtrate levels for TOC and UV_{254} absorbance in tabular form for each 30 day period of operation, and
  - Provide feed and filtrate concentrations of any measured water quality parameters in tabular form for each 30 day period of operation.
- Removal of indigenous bacteria (TC and HPC):
  - Provide feed and filtrate levels for TC and HPC bacteria in tabular form for each 30 day period of operation, and
  - Provide values for TC and HPC log removal in tabular form for each 30 day period of operation.
- Removal of DBPs (optional):
  - Provide feed and filtrate concentrations of Total Trihalomethanes (THM) and haloacetic acids (HAA6) formed during SDS testing for each 30 day period of operation.

12.0 TASK 4: REPORTING OF MEMBRANE PORE SIZE (OPTIONAL)

12.1 Introduction

One mechanism by which low pressure membranes can remove microorganisms from water is physical sieving. Those organisms that are larger than the largest "pore size" of the membrane are retained by the membrane; those that are smaller than the pore size pass through the membrane into the filtrate. Quantification of the membrane pore size distribution is one critical factor in assessing

whether a membrane has the potential to remove a microorganism from a feed water. Membrane pore size records will be provided for informational purposes only and will not be verified by the ETV Program. While it is best to characterize membranes microbially, it is still useful to compare the manufacturer's membrane pore size distribution with the measured membrane microbial removal from Task 8D (Section 16.2.8), if bench-scale microbial tests are conducted. Low-pressure membrane manufacturers report a "nominal" pore size, a size above which a specified percentage of particles of a certain nature are rejected under select conditions.

12.2 Experimental Objectives

The objective of this task is to report the 90% and maximum pore size for the membrane tested. This is a suggested task.

12.3 Work Plan

Membrane manufacturers will have determined the pore size distribution for their membranes. The 90% and maximum pore size should be reported and the general methods used for determining the values should be discussed. For some membranes, reporting nominal molecular weight cutoff may be more appropriate than pore size distribution. In these cases, the former may be reported with a description of its methods for determination.

13.0 TASK 5: MEMBRANE INTEGRITY TESTING

13.1 Introduction

Monitoring of membrane integrity is necessary to ensure that an adequate barrier is continuously being provided by the membrane surface. In this task, existing methods of direct and indirect membrane integrity monitoring are identified and explained. These described techniques may include, but are not limited to:

13.1.1 Direct Monitoring Methods

- Air pressure-hold testing;
- Diffusive air flow testing;
- Bubble point testing;
- Sonic wave sensing, and
- Water displacement test.

13.1.2 Indirect Monitoring Methods

- Particle counting, and
- Particle monitoring.

13.2 Experimental Objectives

The objective of this task is to demonstrate the methodology to be employed for monitoring membrane integrity and to verify integrity of membrane modules. Demonstration of the efficacy of either direct or indirect monitoring techniques is a requirement of this task.

13.3 Work Plan

The FTO shall clearly describe the most appropriate methods for monitoring of membrane integrity in the PSTP. The techniques listed above are intended to serve as examples of both direct and indirect methods for monitoring membrane integrity. These direct and indirect monitoring methods should be used together to provide consistent and sensitive evaluation of membrane system integrity.

13.3.1 Direct Monitoring Methods

Air Pressure-hold Test: The air pressure-hold test is one of the direct methods for evaluation of membrane integrity. This test can be conducted on several membrane modules simultaneously; thus, it can test the integrity of a full rack of membrane modules used for full-scale systems. Minimal loss of the held pressure (generally less than 1 psi every five minutes) at the filtrate side indicates a passed test, while a significant decrease of the held pressure indicates a failed test.

Diffusive Air Flow Test: The diffusive air flow test uses the same concept of the air pressure-hold test, but is performed by monitoring the displaced liquid volume due to the leaking air from compromised fiber(s). This test is more sensitive than the air pressure test because it is technically easier and is more accurate for measurement of small variations in liquid volume rather than small variations in air pressure.

Bubble Point Test: Bubble point testing can identify the fiber or seal location that is compromised in a membrane module. The test is typically performed after the compromised module is identified by a sonic sensor or any other monitoring method. After identifying the compromised fiber, it can then be isolated from the module by adding an epoxy glue to its inlet, or by inserting a pin with the same fiber diameter at the fiber inlet and outlet edges.

Sonic Sensing: Sonic sensors may also be used to detect the integrity of the membrane modules. The equipment consists of a sound wave sensor attached to a headphone. The headphones are manually placed at the top, middle, and bottom of the membrane module during the air-pressure hold test to detect any sound waves created by potential air bubbles leaking through a damaged fiber. The difference in audio sound between an intact and a compromised membrane may be identified by the equipment operators. Sonic sensing is only a qualitative tool for detecting loss of membrane fiber integrity, and therefore this test must be followed by a more quantitative method for evaluation of membrane integrity.

Water Displacement Test: The water displacement test is similar to the diffusive air flow test with the exception that the volume of water displaced as a result of an integrity breach is measured instead of the flow of air through a breach.

13.3.2 Indirect Monitoring Methods

Indirect methods of monitoring membrane integrity are those that do not evaluate the membrane itself, but rather use a surrogate parameter (such as particles) for assessing the membrane's condition. Continuous monitoring of particles in the filtrate stream is an indirect method for evaluating treatment reliability.

Several particle detection devices may be used for monitoring quality of the filtrate stream in terms of particles in the filtrate stream including: on-line and batch particle counters, and on-line particle monitors.

Particle Counting: Refer to Task 7, QA/QC for particle counting methodology.

Particle Monitoring: Particle monitoring is based on dynamic light obscuration. The instrument measures fluctuations in intensity of a narrow light beam which is transmitted through the sample. A fluctuating AC signal from a constant DC signal is measured by a detector and amplified. The monitor does not count particle sizes, but rather provides an index (ranging from 0 to 9,999) of the water quality. No calibration is required for this instrument since the output is a relative measurement of water quality. The potential advantages of this monitor are its low cost and ease of operation compared to particle counters.

13.4 Evaluation Criteria and Minimum Reporting Requirements

- Criteria established by the manufacturer and its designated FTO in selection of the integrity testing method:
  - Plot table of membrane integrity results as appropriate, and
  - Plot graph of integrity test results over time where appropriate for selected methodology.

14.0 TASK 6: DATA HANDLING PROTOCOL

14.1 Introduction

The data management system used in the verification test shall involve the use of computer spreadsheets and manual recording of operational parameters for the membrane equipment on a daily basis.

14.2 Experimental Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data to ensure that the FTO provides sufficient and reliable operational data to NSF for verification purposes.

14.3 Work Plan

The following procedure has been developed for data handling and data verification to be used by the FTO. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used

for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of membrane equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

In the case when a SCADA system is not available, field testing operators shall record data and calculations by hand in laboratory notebooks. (Daily measurements shall be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook shall provide carbon copies of each page. The original notebooks shall be stored on-site; the carbon copy sheets shall be forwarded to the project engineer of the FTO at least once per week during each seasonal one-month testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include a description of the membrane equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time. Following data entry, the spreadsheet shall be printed out and the print-out shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet shall be printed out. Each step of the verification process shall be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each membrane test run) shall be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA-accredited laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the field testing operator. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

15.0 TASK 7: QUALITY ASSURANCE/QUALITY CONTROL

15.1 Introduction

QA/QC for the operation of the membrane equipment and the measured water quality parameters shall be maintained during the verification test.

15.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the verification test. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the manufacturer or by

Standard Methods. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to determine exact conditions at the time of testing.

15.3 Work Plan

When developing the Quality Assurance Project Plan (QAPP) within the PSTP, the FTO should refer to Chapter 1, Section 6.0 Quality Assurance Project Plan, in addition to the information provided herein. All of the requirements and guidelines described in Chapter 1 shall be included in the development of the PSTP. In addition to the general ETV Program QA/QC described in Chapter 1, the PSTP shall incorporate the specific adsorptive media QA items detailed in this section.

Equipment flowrates and associated signals should be documented and recorded on a routine basis. A routine daily walk through during testing shall be established to check that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to confirm that any chemicals are being fed at the defined flowrate into a flowstream that is operating at the expected flowrate and that the chemical concentrations are correct. In-line monitoring equipment such as flowmeters, etc. shall be checked to confirm that the readout matches with the actual measurement (i.e., flowrate) and that the signal being recorded is correct. The items listed in this task are in addition to any specified checks outlined in the analytical methods.

15.4 Daily QA/QC Checks:

- Chemical feed pump flow rate checked daily volumetrically over a specific time period to confirm instrument reading;
- In-line turbidimeters flow rate checked daily volumetrically over a specific time period to confirm instrument reading;
- In-line turbidimeter readings checked daily against a properly calibrated bench-top model; and
- Batch and in-line particle counters flow rate checked daily volumetrically over a specific time period to confirm instrument reading.

15.5 QA/QC Checks Performed Every Two Weeks:

- In-line flowmeters/rotameters (check flow volumetrically over a specific period of time to confirm the instrument reading, and if necessary, clean equipment to remove any foulant buildup).

15.6 QA/QC Checks Performed Each Testing Period:

- In-line turbidimeters (clean out reservoirs, if necessary, and recalibrate);
- Differential pressure transmitters (check gauge readings and electrical signal using a pressure meter);
- Tubing (check condition of all tubing and connections, replace if necessary); and
- Particle Counters (perform check of microsphere calibration in the field).

15.7 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of raw water and filtered water quality are described in the section below. In-line equipment is recommended for its ease of operation and because it limits the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. In-line equipment is recommended for measurement of turbidity and for particle counting for feed water and is required for measurement of turbidity and for particle counting for filtered water.

15.7.1 pH

Analyses for pH shall be performed according to *Standard Method* 4500-H^+. A three-point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

15.7.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Method* 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1°C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1°C to +51°C, subdivided in 0.1°C increments, would be appropriate for this work.)

15.7.3 Turbidity Analysis

Turbidity analyses shall be performed according to *Standard Method* 2130 or EPA Method 180.1 with either an in-line or bench-top turbidimeter. In-line turbidimeters shall be used for measurement of turbidity in the filtrate waters, and either an in-line or bench-top turbidimeter may be used for measurement of the feed water (and concentrate where applicable).

During each verification testing period, the in-line and bench-top turbidimeters shall be left on continuously. Once each turbidity measurement is complete, the unit shall be switched back to its lowest setting. All glassware used for turbidity measurements shall be cleaned and handled using lint-free tissues to prevent scratching. Sample vials shall be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The FTO shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

15.7.3.1 Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument shall serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of verification testing and on a weekly basis

using primary turbidity standards of 0.1, 0.5, and 3.0 nephelometric turbidity units (NTU). Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to check calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples shall consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity. For the case of cold water samples that cause the vial to fog preventing accurate readings, the vial shall be allowed to warm up by partial submersion in a warm water bath for approximately 30 seconds.

15.7.3.2 In-line Turbidimeters. In-line turbidimeters shall be used for measurement of turbidity in the filtrate water during verification testing and must be calibrated and maintained as specified in the manufacturer's O&M manual. It will be necessary to check the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments, the readings should be comparable. If the comparison suggests inaccurate readings, then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted using lint-free paper to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic checks of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. The LED readout should also be checked to ensure that it matches the data recorded on the data acquisition system, if the latter is employed.

15.7.4 Particle Counting

In-line particle counters shall be employed for measurement of particle concentrations in filtrate waters. However, either a bench-top or an in-line particle counter may be used to measure particle concentrations in the feed water, concentrate (where applicable) and pretreated waters (where applicable). Laser light scattering or light blocking instruments are recommended for particle counting during verification testing. However, other types of counters such as Coulter counters or Elzone counters may be considered for use if they can be configured to provide continuous, in-line monitoring for the filtrate product water stream. The following discussion of operation and maintenance applies primarily for use of laser light blocking instruments.

The following particle size ranges shall be monitored by both in-line and bench-top analytical instruments during the verification testing:

- 2-3 μm;
- 3-5 μm;
- 5-7 μm;
- 7-10 μm;
- 10-15 μm; and
- 15 μm.

The FTO shall be required to document any problems experienced with the monitoring particle counting instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

Use of particle counting to characterize feed water and filtered water quality is required as one surrogate method for evaluation of microbiological contaminant removal.

15.7.4.1 Bench-top Particle Counters. All particle counting shall be performed on-site. The particle sensor selected must be capable of measuring particles as small as 2 μm. There should be less than a 10% coincidence error for any one measurement.

Calibration. Calibration of the particle counter is generally performed by the instrument manufacturer. The calibration data will be provided by the manufacturer for entry into the software calibration program. Once the data has been entered it should be verified using calibrated commercially-available particle standards or methods. This calibration shall be verified at the beginning of each verification testing period.

Maintenance. The need for routine cleaning of the sensor cell is typically indicated by: 1) illumination of the sensor's "cell" or "laser" lamps, 2) an increase in sampling time from measurement to measurement, or 3) an increase in particle counts from measurement to measurement. During the ETV test, the sensor's "cell" and "laser" lamps and the sampling time will be checked periodically. The number of particles in the "particle-free water" will also be monitored daily.

Particle-Free Water System. "Particle-free water" (PFW) will be used for final glassware rinsing, dilution water, and blank water. This water will consist of de-ionized (DI) water that has passed through a 0.22-μm cartridge filtration system. This water is expected to contain fewer than 10 total particles per mL, as quantified by the on-site particle counter.

Glassware Preparation. All glassware used for particle counting samples shall consist of beakers designed specifically for the instrument being used. Glassware will be cleaned after every use by a triple PFW rinse. Sample beakers will then be stored inverted.

Dedicated beakers will be used at all times for unfiltered water (raw, pre-oxidized, flocculated), diluted unfiltered water, filtered water, and PFW. When several samples are collected from various equipment sampling points during one day, the appropriate beakers will be hand-washed as described above, and then rinsed three times with sample prior to collection.

Other materials in contact with the samples, including volumetric pipettes, volumetric flasks, and other glassware used for dilution, will also be triple-rinsed with both PFW and sample between each measurement.

Sample Collection. Beakers should be rinsed with the sample at least three times prior to sample collection for particle counting. Sample taps should be opened slowly prior to sampling. Sudden changes in the velocity of flow through the sampling taps should be avoided immediately prior to sample collection to avoid scouring of particles from interior surfaces. A slow, steady flow rate from the sample tap will be established and maintained for at least one minute prior to sample collection. The sample will be collected by allowing the

sample water to flow down the side of the flask or beaker; thereby minimizing entrainment of air bubbles.

Dilution. The number of particles in the raw and pretreated waters (where applicable) is likely to exceed the coincidence limit of the sensor. If so, these samples will be diluted prior to analysis. In all cases, PFW will be used as dilution water. When necessary, dilutions will be performed as follows:

- Dilution water will be dispensed directly into a 500-mL volumetric flask;
- A volumetric pipette (i.e. 10-mL for a 50:1 dilution) will be used to collect an aliquot of the sample to be diluted (stock);
- The appropriate volume of the stock will be slowly added to the volumetric flask containing the dilution water;
- The volumetric flask will be slowly filled to the full-volume etch with dilution water; and
- The volumetric flask will be inverted gently and then its contents will be poured slowly into the appropriate 500-mL flask for analysis.

During each of the above steps, care will be taken to avoid entrainment of air bubbles; thus, samples and dilution water will flow slowly down the side of containers to which they are added. Excessive flow rates through pipette tips, which can cause particle break-up, will be avoided by use of wide-mouth pipettes. Sample water will be drawn into and out of pipettes slowly to further minimize particle break-up.

Actual particle counts in a size range for diluted samples will be calculated based on the following formula:

$$Sample\ Particle\ Concentration = \frac{\{MP - (1 - X) \times PF\}}{X}$$

where MP is the measured particle concentration in the diluted sample, PF is the measured particle concentration in the particle-free water, and X represents the dilution factor. For a 25:1 dilution, the dilution factor would be 1/25, or 0.04. The expression for the dilution factor is provided by the following equation:

$$Dilution\ Factor = X = \frac{Volume\ Sample}{Addition\ of\ Volume\ Sample + Volume\ Dilution\ Water}$$

Particle Counting Sample Analysis. To collect samples for particle counting, at least 200 mL of each water sample to be counted (diluted or not) should be collected in the appropriate beaker. The beaker will be placed into the pressure cell and counting will take place in the "auto" mode of the instrument. Four counts will be made of each sample. The first count will serve to rinse the instrument with the sample; data from this count are discarded. Data from the subsequent three counts will be averaged, and the average value will be reported as the count for that sample.

15.7.4.2 In-line Particle Counters. In-line particle sensors selected for use must have capabilities for measurement of particles as small as 2 μm and have a coincidence error of

less than 10%. The particle counter manufacturer shall provide data and methods that the in-line particle sensors meet these criteria or an independent third party shall check that the in-line particle sensor meets the above criteria. The particle counter manufacturer shall provide the methods for demonstration of coincidence error.

The sensors of the in-line units must also be provided with a recent (two months before the start of testing) manufacturer calibration. The calibration shall be verified by measurement of the individual and cocktail suspensions of the monospheres as described for the batch counter; however, in this case the samples must be fed in-line to the counters.

No dilution of the filtered water samples shall be conducted. The data acquired from the counters shall be electronically transferred to the data acquisition system. If it is known that a particular sensor will not be used for a period of several days or more, refer to the manufacturer recommendations for an appropriate storage protocol.

15.8 Organic Parameters: TOC and UV_{254} Absorbance

Samples for analysis of TOC and UV_{254} absorbance shall be collected in glass bottles supplied by the laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held, and shipped in accordance with *Standard Method* 5010B. Storage time before analysis shall be minimized, according to *Standard Methods*.

15.9 Microbial Parameters: TC and HPC Bacteria

Samples for analysis of TC and HPC bacteria shall be collected in bottles supplied by the laboratory and shipped with an internal cooler temperature of approximately 4°C to the analytical laboratory. Samples shall be processed for analysis by the state-certified or third party- or EPA-accredited laboratory within the time specified for the relevant method. Laboratory shall keep the samples at approximately 4°C until initiation of analysis. TC densities shall be reported as most probable number per 100 mL (MPN/100 mL) or as TC densities per 100 mL. HPC densities shall be reported as colony forming units per milliliter (cfu/mL).

15.10 Inorganic Samples

Inorganic chemical samples, including, alkalinity and hardness, shall be collected and preserved in accordance with *Standard Method* 3010B, paying particular attention to the sources of contamination as outlined in *Standard Method* 3010C. The samples shall be refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C during shipment. Samples shall be processed for analysis by a laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

15.11 SDS DBP Test Protocol

The SDS DBP test simulates full-scale disinfection by spiking a water sample with a disinfectant and holding the spiked sample in the dark at a designated temperature and contact time. For this testing, one of two SDS approaches may be employed. The conditions selected for SDS evaluation may be those that most closely approximate the detention time and chlorine residual found in the distribution system at the location of verification testing. Alternatively, the UFC specified by the ICR may be

adopted. The UFC, as specified under the ICR stipulate that the following set of conditions will be employed:

- Incubation period of 24 +/- 1 hour;
- Incubation temperature of 20 +/- 1.0 °C;
- Buffered pH of 8.0 +/- 0.2; and
- 24-hour chlorine residual of 1.0 +/- 0.4 mg Cl_2/L.

For each SDS sample, three incubation bottles will be set up. At the end of the incubation period, each sample will be analyzed for the final disinfectant residual and the sample with the residual closest to the 1.0 +/- 0.4 mg/L range will be used for specified DBP analyses.

One liter, amber colored bottles with Teflon lined caps will be used to store the SDS samples during incubation. These bottles will be stored in a temperature-controlled incubator at the specified temperature.

All glassware used for preparation of the reagents will be chlorine demand free. Chlorine demand free glassware will be prepared by soaking glassware in a 50 mg/L chlorine bath for a period of 24 hours. At the end of this time, all glassware will be rinsed three times with organic-free water that has a TOC concentration of less than 0.2 mg/L. Glassware will then be dried at room temperature for a period of 24 hours. During the drying process, bottle openings will be covered with aluminum foil to prevent contamination.

Reagents will be prepared as follows:

15.11.1 Chlorine Stock Solution Preparation

The stock solution is prepared by adding an estimated volume of 6% reagent-grade NaOCl into a 500-mL, chlorine demand free, bottle containing an estimated amount of organic-free water. To minimize the dilution error, the chlorine stock solution is required to be at least 50 times stronger than the chlorine dose required.

15.11.2 Preparation of Additional Chemicals

Refer to *Standard Method* 4500-Cl F for the preparation method of DPD indicator, FAS standard and buffer solution. The phosphate buffer solution should be prepared as instructed in *Standard Method* 4500-Cl F.

15.11.3 Sample Collection and Incubation

The samples will be collected in a 1-L amber bottle and stored in the dark at the predetermined temperature. Samples will be adjusted to the designated pH and chlorine residual for the distribution system at the chosen site. In the case that the UFC are adopted for SDS testing, the samples will be adjusted to pH 8.0 +/- 0.2 using 1M HCl or NaOH and will then be dosed with the appropriate dosage of chlorine to yield a chlorine residual of 1.0 +/- 0.4 mg Cl_2/L after the specified 24-hour storage period. The samples will be capped head-space free and stored for the appropriate time (24 hours for UFC) in the dark at the appropriate incubation temperature.

15.11.4 Analytical Measurements

Residual free chlorine measurements will be conducted according to *Standard Methods* 4500-Cl G. DPD Colorimetric Method. Specific parameters to be measured and recorded are outlined in the specific task descriptions.

16.0 TASK 8: MICROBIAL REMOVAL

The manufacturer shall choose to have either a field microbial seeding study or bench-scale microbial testing performed as part of its ETV testing. Section 16.1 outlines the requirements for a field seeding study and Section 16.2 outlines the requirements for a bench-scale test.

16.1 Field Seeding Study

16.1.1 Introduction

Absolute removal of *Giardia* and *Cryptosporidium* has been well documented for only a selected number of MF and UF processes. Virus removal capabilities have not been well documented extensively for membrane processes. In this task, the effectiveness of membrane processes for microbial removal shall be evaluated by use of seeding studies. The field seeding studies, if chosen, shall be conducted with protozoa (*Giardia* and *Cryptosporidium*) and/or MS2 virus, and shall be performed during the required test runs conducted for Task 1.

16.1.2 Experimental Objectives

The experimental objective of this task is to characterize the membranes in terms of microbial removal. The type of seeding studies (protozoa, viruses or both) conducted as a part of this task will be left to the discretion of the manufacturer.

16.1.3 Work Plan

During the seeding studies, the FTO shall conduct the microbial seeding studies in the field as described in the following procedures and sample collection sections. The FTO shall then submit collected seeding water samples to a state-certified or third party- or EPA-accredited laboratory for microbial testing.

16.1.3.1 Organisms Employed for Field Challenge Experiments. Table 5 presents the different microorganisms that may be used for the field microbial rejection studies. Two protozoan cysts and one virus were identified for use in these seeding studies. These organisms were chosen to provide some variety in the types and sizes of microorganisms to indicate the range of membrane microbial removal capabilities. *Giardia* cysts were selected since this microorganism is one of the driving forces behind the SWTR. The model microorganism used may either be *Giardia muris*, a non-pathogenic species, or *Giardia lamblia*, a pathogenic species. *Cryptosporidium* is another important protozoan that is potentially targeted for regulation in the future. *Cryptosporidium parvum* is recommended for use in these studies.

Table 5. Microorganisms Recommended for Microbial Seeding

Microorganism	Model	Source
Protozoa	*Giardia muris*	seeded
	Cryptosporidium parvum	seeded
Virus	MS2 bacteriophage	seeded

MS2 bacterial virus was identified for use as the model virus for the microbial challenge studies. MS2 bacteriophage is the virus of choice for challenge studies because it is similar in size (0.025 μm), shape (icosahedron) and nucleic acid (RNA) to polio virus and hepatitis. This bacterial virus is the suggested organism to use in the SWTR Guidance Manual when conducting studies of microbial removal (USEPA, 1989).

It is recognized that in many cases it may not be possible to employ viable protozoan cysts and oocysts for seeding studies, depending upon where the equipment verification is being performed. In such a case, *Cryptosporidium* organisms fixed in no more than 10% formalin may be used. *Giardia* organisms fixed in no more than 5% formalin may be used. Alternatively, the organisms may be heat-fixed. Introduction of surrogates or alternatives for formalin- or heat-fixed protozoa and MS2 virus to this testing plan shall be based upon peer-reviewed studies and proven experimental methodologies and shall only be allowed after approval from NSF. Organism stocks received from appropriate suppliers shall be stored under refrigeration in the dark at 4°C until use in the seeding studies. Aliquots for use in each seeding study shall then be delivered on ice to the equipment on the day of the testing.

16.1.3.2 Microbial Seeding Protocols. Microbial challenges shall be conducted as batch seeding tests, with one seeding study conducted per testing period. In the batch testing mode, each microorganism to be used for challenge testing shall be seeded to a constant volume of feed water (potentially 50 to 200 gallons). Sufficient volume of stock suspension shall be created in the seeding tank to sustain membrane operation for a minimum of 30 minutes. For the protozoa seeding studies, the final seeding concentration in the feed water tank should be high enough to demonstrate at least 4 log removal of *Giardia* and *Cryptosporidium*. For the virus seeding studies, the final seeding concentration in the feed water tank should also be high enough to demonstrate at least 4 log removal of viruses. In order to show a 4 log removal of microorganisms, it is recommended that feed water contain 10^6 to 10^7 microorganisms in a challenge test.

The seeding experiments shall be conducted under the operating conditions in which the microorganisms would be most likely to penetrate the membrane. These conditions may include the high flux employed during the testing period. Initiation of the seeding study shall occur immediately after backwashing the membrane. Furthermore, the membrane seeding studies should be performed as soon as possible following a chemical cleaning procedure. If the membrane equipment is operated with automatic backwash routines, the addition of seed microorganisms should be performed immediately at the conclusion of a backwash routine to evaluate microbial removal in the absence of a cake layer on the membrane surface. The frequency of backwash may need to be adjusted during microbial challenge to allow sufficient time for sample collection.

The feed suspension of protozoa or viruses shall be prepared in the seeding tank by adding the concentrated stock suspension(s) of organisms into a feed water reservoir. The reservoir

shall be completely mixed during preparation of the seeded feed water and throughout the filtration period. After the addition of protozoa or viruses to the seeding tank and before the initiation of filtration, samples shall be collected to establish the initial titer of the microorganisms. Once filtration has begun, transmembrane pressure, filtrate flux and recirculation rate (where appropriate) shall be recorded. Sample volumes of the feed water, filtrate water and backwash water shall be recorded. An EPA-accredited laboratory shall be selected for analysis of appropriate microbial species, and sample volumes shall be processed according to the instruction provided by the EPA-accredited laboratory. At the end of sample preparation, the prepared samples shall be shipped to the EPA-accredited laboratory for analysis.

During the protozoa studies, a minimum of one sample from the feed water and three samples of the filtered water shall be prepared per seeding study (per season) for analysis by the EPA-accredited laboratory. During MS2 viral seeding studies, a minimum of one sample from the feed water, three samples from the filtrate water and one sample from the backwash water shall be collected. The first permeate sample for viral seeding studies shall be collected within the first 30 seconds of initiating filtration of the seeded waters, and subsequent samples shall be collected at 10 to 15 minute intervals. Each sample shall be collected in sterile 250 mL bottles. Bottles shall be stored at 4°C and processed within 24 hours.

16.1.4 Analytical Schedule

16.1.4.1 Water Quality Sampling. During microbial seeding studies, sampling of feed waters and filtrate waters shall be performed with daily measurement of temperature (feed only), pH, turbidity and particles.

16.1.4.2 Operational Data Collection. Operational data, as required by Task 1 shall be collected at the time of each seeding experiment.

16.1.5 Evaluation Criteria and Minimum Reporting Requirements

- Removal of *Giardia* and *Cryptosporidium*:
  - Provide feed water and filtrate levels of *Giardia* and *Cryptosporidium* in tabular form;
  - Create bar chart of log removal of microorganisms seeded (*Giardia* and *Cryptosporidium*).
- Removal of virus:
  - Provide influent and effluent levels of *virus* in tabular form, and
  - Create bar chart of log removal of microorganisms seeded (*viruses*).

16.2 Bench-Scale Characterization of Membranes Using Microbial Profiling

16.2.1 Introduction

One of the primary drivers for the use of low-pressure driven membranes for treatment of drinking water supplies has been the increased emphasis on the removal of microorganisms. Low-pressure membrane processes have been classified traditionally as MF or UF. There is currently no agreement on specifications that distinguish MF from UF. The traditional method for distinguishing UF from MF is pore size distribution or molecular weight cutoff.

MF membranes are often considered to have pore sizes ranging from 0.05 μm to 5 μm and UF membranes from 0.005 μm to 0.05 μm. There is considerable overlap between where one may consider MF to begin and UF to end. Moreover, pore size distribution does not provide an accurate or empirically based method to predict microbial removal. The actual classification of these membranes for product marketing relies primarily upon the manufacturer. Of particular note, microbial removal does not currently play a role in determining whether a membrane is classified as MF or UF. This point leads to confusion in the water community as to the classification of low-pressure membranes. If membranes are to be employed on a more widespread basis for microbial removal, then their classification should be based on their capability to remove microorganisms, not on their pore size distribution.

Microbial removal is usually evaluated through pilot testing. However, rigorous microbial challenge studies at pilot scale are often prohibitively costly. Since pilot studies are typically conducted at water facilities, opportunities for microbial challenge studies may be limited because of the potential hazard of working with microorganisms in proximity to drinking water supplies. Further, membranes are most vulnerable to microbial passage when they are first put online. There are numerous complexities of sampling for microbial agents immediately after pilot plant startup (such as collecting a sample rapidly and aseptically). The inability to sample a clean membrane as soon as it is placed online may provide inconsistent results due to cake layer accumulation or pore constriction from adsorption of natural organic matter onto the membrane.

This TSTP provides a protocol to evaluate microbial removal by membranes at bench scale. Materials for most low-pressure membrane filtration modules used in drinking water treatment have a hollow fiber geometry. Nonetheless, this TSTP can be employed for other geometries (i.e., tubular) with little modification. Its intent is to provide a widely accepted, standardized methodology with which to characterize membranes from a microbial perspective. The absence of natural water constituents in the feed will allow accurate assessment of the capability of membrane materials to remove microorganisms.

The TSTP is designed for scientific rigor, but also for ease of implementation by a qualified laboratory, denoted as laboratory testing organization throughout this document. The data generated from execution of the protocol are intended to provide utilities, engineers and regulators with the necessary information to make informed decisions about current and future membrane products that are being (or will be) employed for treatment of water supplies. As an option outside of ETV testing, these procedures may also be used by the manufacturer to determine the membrane lot acceptance of a membrane filtration media when challenge testing is needed to demonstrate removal for a lot acceptance.

16.2.2 General Approach

The general approach to the membrane bench testing is to conduct microbial challenge studies under conditions that the microorganisms are most likely to penetrate the membrane using a standardized Low-Pressure Membrane Testing Unit. The primary operational variable shall be transmembrane pressure, which shall be applied under direct flow conditions. Feed water containing the selected microorganisms shall be applied continuously to the membrane for the duration of the challenge. No backwashing or recirculation shall be employed during the experimental run. The challenge studies shall be executed through a

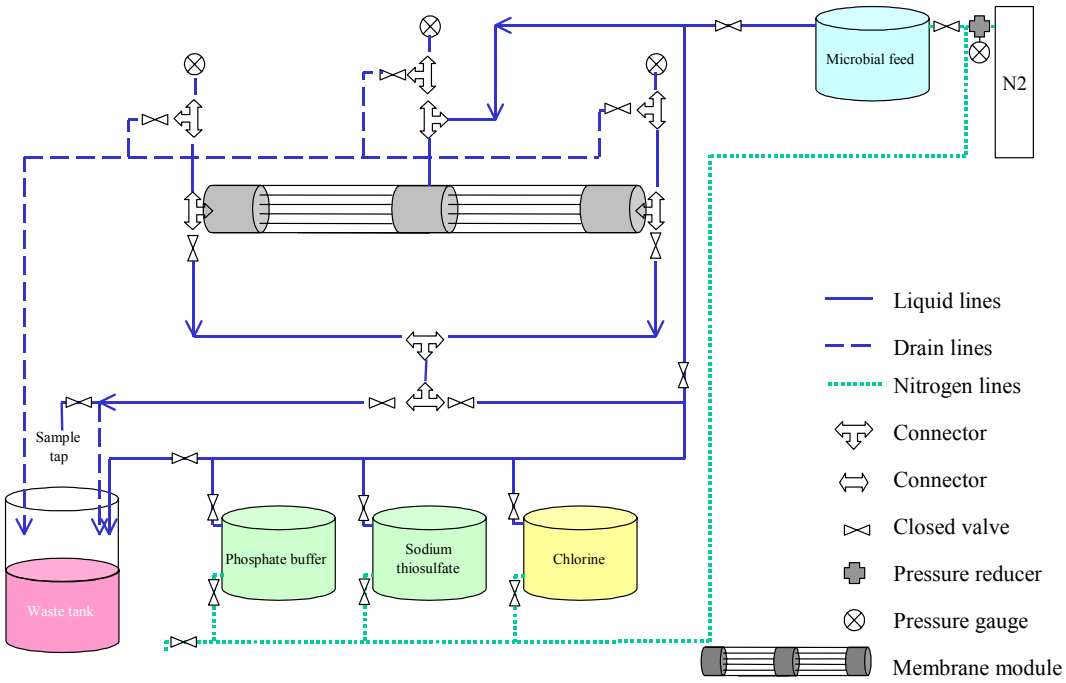
series of tasks as noted below and discussed in more detail after a discussion of the membrane testing unit experimental setup.

Task 8A – Establish Filtrate Flux;
Task 8B – Perform Membrane Cleaning and Backwashing;
Task 8C – Perform Membrane Integrity Testing;
Task 8D – Conduct Microbial Removal Experiments; and
Task 8E – Execute Data Handling Protocol.

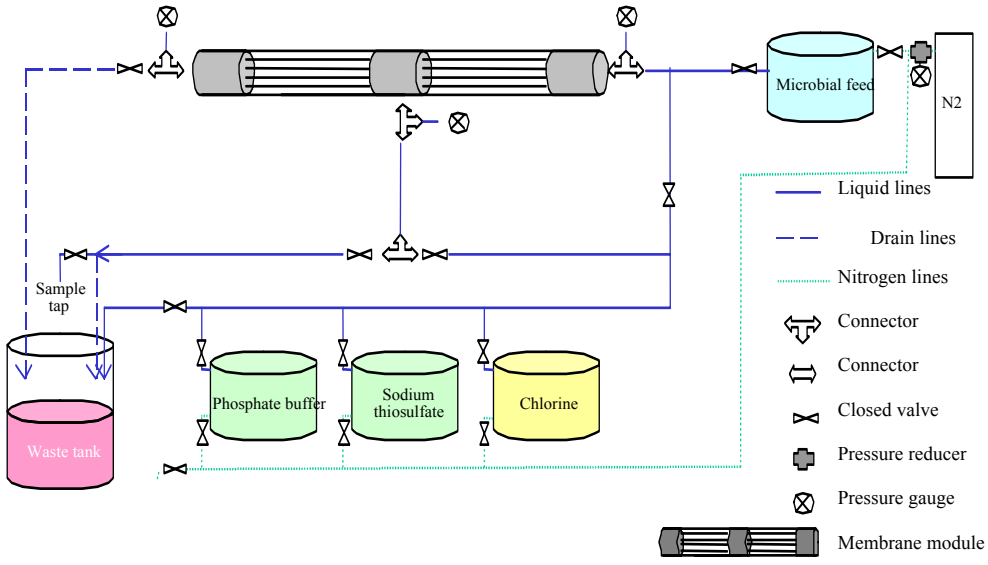
16.2.3 Membrane Filtration Unit Experimental Set Up

16.2.3.1 Low-Pressure Membrane Testing Unit. The low-pressure membrane testing unit in this document refers to the membrane module, associated tubing and connections, pressure gauges, tanks and pumps (or nitrogen tanks). The unit can be set up in three different ways, depending on the type of flow configuration necessary for the particular membrane module to be tested. These three different experimental setups for the low-pressure membrane testing unit are illustrated in Figures 2, 3, and 4. The three setups accommodate two pressure-driven flow configurations (inside out and outside in) as well as one outside-in, vacuum driven configuration. The same low-pressure membrane testing unit can be employed for each flow configuration with minor tubing changes.

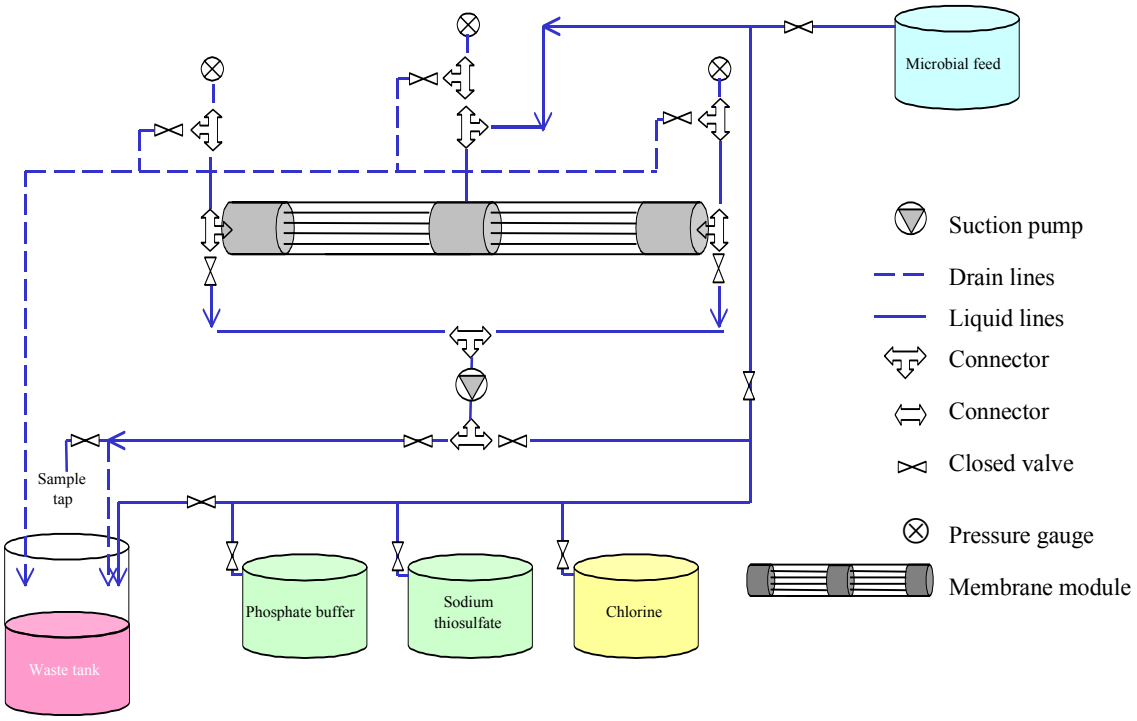
The low-pressure membrane testing unit is comprised of five separate tanks: one tank provides a microbial feed for the challenge studies; three other tanks (chlorine or other biocidal agent, sodium thiosulfate and phosphate buffer) are employed for backwashing and/or cleaning the membrane module between experimental runs. A fifth tank is used to collect waste. Pressurized nitrogen gas is employed to provide system pressure, since mechanical pumping can cause perturbations in pressure application. A vacuum system is employed for submersible vacuum driven applications. Details of materials used for construction of the low-pressure membrane testing unit are presented in Appendix 2C.



Schematic of low pressure membrane filtration unit – Outside/In flow configuration, pressure-driven
Figure 2



Schematic of Low-Pressure Membrane Test Unit – Inside/out flow configuration, pressure driven
Figure 3



Schematic of low pressure membrane filtration unit – Outside/in flow configuration vacuum driven
Figure 4

16.2.3.2 Bench-Scale Modules Used in Challenge Testing. Membranes exhibit product variability, and the degree of variability will depend on a number of factors specific to the product and the manufacturing process. Furthermore, product variability is manifested in different aspects of product performance and characteristics. Membranes may exhibit variability with respect to removal efficiency, pore size distribution, bubble point, productivity, and membrane area among other characteristics. All of these aspects of product variability can be important considerations for a specific application; however, variability in removal efficiency is of primary concern in the context of challenge testing.

The membrane material used by the manufacturer to fabricate the bench modules will be obtained from full-scale modules or membrane materials from their production line. The membrane modules used for evaluation in the low-pressure membrane testing units shall be based on the statistical distribution of nondestructive performance test results, as described below, or on an alternative approach provided by the manufacturer and laboratory or FTO. If an alternative approach is desired, it shall be reviewed and approved by NSF and the EPA under the ETV Program prior to implementation. Alternative approaches shall take into account product variability in terms of efficacy of microbial removal and may depend upon the specific characteristics of the membrane.

Nondestructive Membrane Test and Quality Control Release Values. A nondestructive performance test is a physical test that characterizes a fundamental property of the membrane that can be correlated to some aspect of process performance, and which does not alter or damage the membrane. In the context of challenge testing, the nondestructive performance test must be correlated to the removal efficiency of the target organism. An example of such a test is the bubble point test, the results of which can be directly related to the size of the largest pore in a membrane. Manufacturers often use such nondestructive testing as a means of quality control and assurance, and in many cases such a test is applied to every production module. The results of such extensive testing can provide a good estimate of product variability as it relates to removal efficiency.

The nondestructive performance test is used to assure the removal efficiency of production modules in the following manner. The challenge test demonstrates the removal efficiency of the specific module(s) evaluated, and these modules are characterized through application of the nondestructive performance test that is used as part of the manufacturer's routine quality control and assurance program. The results of the nondestructive performance test applied to the module(s) evaluated during the challenge test establish a control limit for the nondestructive performance test.

The nondestructive performance serves as the basis for confirming the performance of membrane modules that are not directly challenge tested. Manufacturers that have historically performed nondestructive testing for the purpose of product quality control and assurance can use this information to characterize the variability of a product line. Additionally, a manufacturer may have established a quality control release value for the nondestructive performance test that provides a minimum cutoff for an acceptable product. Based on these considerations, selection of membrane materials used in bench-scale modules for challenge testing should be based on nondestructive performance test results.

Since the challenge test is used to establish the control limit for the nondestructive performance test that production modules must meet, it would be prudent to test modules

with nondestructive performance test results that are close to the quality control release value. The rationale behind testing a worst-case module is that it allows for fewer modules to be tested while still providing a means of verifying the removal efficiency of production modules through application of the nondestructive performance test. This approach for module selection may be especially useful when complete removal of the challenge organism is anticipated for all modules of the product line.

It should be noted that many nondestructive performance tests that are suitable for evaluating the ability of a membrane to remove small organisms, such as *Cryptosporidium,* will not apply to very small ones, such as viruses. As an example, the bubble point test cannot typically be applied at a pressure high enough to achieve a resolution on the order of the size of a virus. In such cases, other manufacturing quality control procedures would be necessary to assure virus removal capabilities of production modules. These may include internal quality control testing of the membrane media or testing for acceptance of membrane modules. For more detailed information regarding nondestructive membrane tests and quality control release values, the U.S. Environmental Protection Agency Method Guidance Manual for Membrane Filtration (USEPA, 2003) should be consulted.

Bench-Scale Membrane Module Requirements. Manufacturers shall construct modules with materials as close as possible to their quality control release values, which shall be provided in the final ETV report. Appropriate information on the nondestructive performance tests for these modules or other quality control information shall be provided. A minimum of five bench modules to be employed for each bench-scale microbial characterization shall be provided by the manufacturer. Each module shall have an effective membrane area of approximately 0.1 m^2. The modules shall have an effective length similar to those employed at full scale to have similar pressure drops along the membrane. It is recognized that the length of the bench module may be slightly shorter than that of a full-scale module if the materials to fabricate it are taken directly from a full-scale module. Further, it is recognized that the geometry of some tubular and spiral wound membranes may preclude the use of full scale length modules or elements. In these cases, the length necessary to provide 0.1 m^2 modules should be employed.

Conditioning of Membrane. Before conducting testing, the membranes shall be fully wetted according the manufacturer's specification. After wetting, each module shall be conditioned at a typical filtrate flux (as specified by the manufacturer) for a minimum of four continuous hours before any testing begins. A 0.1 mM phosphate buffer solution (pH 7.0) shall be employed as the feed water. Specific flux shall be monitored once per hour and recorded.

16.2.4 Sequence of Events for Module Testing

Table 6 below presents the general sequence of events for module testing. These events are described in more detail in each of the tasks below.

Table 6. Sequence of Events for Low-Pressure Membrane Module Testing

Event	Comments
Conditioning period for module	Run module for 4 hours
Perform first membrane integrity test	Described in Task 8C
Set filtrate flux; determine specific flux	Conduct before and after five HRTs (described in Task 8A); chemically clean only if necessary (described in Task 8B)
Perform microbial challenge test on module	Described in Task 8D
Determine specific flux	Described in Task 8A
Perform second membrane integrity test	Described in Task 8C
Repeat same sequence with other modules	

16.2.5 Task 8A: Establish Filtrate Flux

16.2.5.1 Introduction. Bench-scale membrane operation in terms of filtrate flux will be established in this task. This task shall be conducted for each of the five membrane modules being tested. This task shall also be repeated after each chemical cleaning (see Task 8B), if chemical cleaning is necessary. Each repetition of this task involves filtration of 0.1 mM phosphate buffer solution for five hydraulic residence times (HRTs) of the low-pressure membrane test unit's module and tubing at a filtrate flux under which microorganisms would be most likely to penetrate the membrane.

16.2.5.2 Experimental Objectives. The objectives of this task are to document the operational conditions under which each of the five membrane modules will be evaluated for microbial removal and then to verify those operational conditions before and after testing of each membrane module. While five modules are the minimum to be evaluated, the testing for more modules is encouraged.

16.2.5.3 Work Plan.

Specification of Filtrate Flux. For this task, the laboratory testing organization shall specify the filtrate flux to be employed during the microbial challenge studies. The microbial challenge experiments shall be conducted at operating conditions under which the microorganisms would be most likely to penetrate the membrane. These conditions shall include the highest operational flux specified by the manufacturer for their membrane using a 0.1 mM phosphate buffer solution and direct flow hydraulic conditions. Note that the pressures to obtain the highest operational flux using a phosphate buffer feed water may not be as high as those observed under field applications. This is because materials in natural water foul the membrane over time, and thus, greater pressures are required to maintain a constant flux. However, under these conditions, microbial removals are less conservative than those under the clean water conditions specified here.

It should also be noted that some hollow fiber, and most spiral wound and tubular membranes often operate in the field under crossflow conditions. Nonetheless, direct flow still represents a worse-case scenario since membrane surface concentration polarization effects do not play

a role under the conditions in which these experiments are to be conducted. Regardless of membrane geometry, the laboratory testing organization shall clearly describe how operational filtrate flux was chosen.

It is anticipated that the filtrate flux will be constant over the time of the experiment, since it is short in duration. However, if greater than 10% specific flux decline of the membrane occurs after filtering 0.1 mM phosphate buffer for five hydraulic residence times of the low-pressure membrane test unit's module and tubing, chemical cleaning shall be performed according to manufacturer specifications. Adjustments to the operational strategy shall be made (such as a decrease in filtrate flux) as necessary. Decisions on adjustments of filtrate flux shall be made by the laboratory testing organization in consultation with the manufacturer.

Microbial challenge studies at additional operational flux conditions are at the discretion of the manufacturer and the designated laboratory testing organization. However, testing of alternate additional operational conditions shall be performed only in addition to the initial flux condition specified in the work plan.

Determination of Specific Flux. On each new module, and before and after each microbial removal experiment, the hydraulic performance of the membrane module shall be evaluated by determining its specific flux. The required parameters to calculate the specific flux include:

- Filtrate flow rate;
- Effective membrane area; and
- Transmembrane pressure.

To evaluate the filtrate flow rate of the membrane, a volume of filtrate is collected over a period of one minute.

The effective membrane surface area is determined as:

$$A = \pi \times (OD) \times (l) \times (n)$$

where: A = effective membrane surface area in m^2 or ft^2;
l = the length of the module in m or ft;
OD = outside diameter (OD) of the fibers (for an outside/in flow configuration) in m or ft; and
n = number of fibers.

For an inside/out flow configuration the effective area becomes:

$$A = \pi \times (ID) \times (l) \times (n)$$

where: A = effective membrane surface area in m^2 or ft^2;
l = the length of the module in m or ft;
ID = inside diameter (ID) of the fibers in m or ft; and
n = number of fibers.

The filtrate flux is determined empirically as:

$$J = \frac{Q_p}{A}$$

where: J = filtrate flux in L/hr/m^2 or gal/day/ft2 (gfd);
Q_p = filtrate flow rate in L/hr or gal/day; and
A = effective membrane surface area in m^2 or ft^2.

In a direct filtration mode, the transmembrane pressure is calculated according to:

$$P_{tm} = P_i - P_p$$

where: P_{tm} = transmembrane pressure in bar or psi;
P_i = pressure at the inlet of the module in bar or psi; and
P_p = filtrate pressure in bar or psi.

The water volume transfer through the membrane per unit of membrane area and driving force is the specific flux (J_s) as described in Section 6.0 of this chapter.

The filtrate flux is normalized by dividing by the transmembrane pressure or net driving force to obtain the specific flux, which is a useful measure by which different membrane operating conditions can be compared to each other.

Temperature corrections to 20°C for filtrate flux shall be made to correct for the variation of water viscosity with temperature. A specific, empirically derived equation developed by the membrane manufacturer may be used to provide temperature corrections. Alternatively, the equation by Streeter and Wiley (1985) may be employed using the effective membrane surface area as described in Section 6.0.

16.2.5.4 Evaluation Criteria and Minimum Reporting Requirements.

- Bar graph of specific flux normalized to 20°C before and after preconditioning for five hydraulic residence times and before and after challenge testing of each module.

16.2.6 Task 8B: Assess Cleaning Efficiency

16.2.6.1 Introduction. Although not anticipated, chemical cleaning of the membrane may be necessary. As such, this task describes the general procedures for conducting chemical cleaning.

16.2.6.2 Work Plan. Cleaning chemicals and cleaning routines shall be based on the recommendations of the manufacturer. The manufacturer and its designated laboratory testing organization shall specify in detail the procedure(s) for chemical cleaning of the membranes. At a minimum, the following shall be specified:

- Cleaning chemicals and concentrations;
- Hydraulic conditions of cleaning (flow, transmembrane pressure);
- Duration of each cleaning step; and
- Initial and final temperatures of chemical cleaning solution.

Each system shall be chemically cleaned using the recommended cleaning solutions and procedures specified by the manufacturer. After each chemical cleaning of the membranes, the system shall be restarted and the initial conditions of specific flux recovery and rejection capabilities shall be tested.

16.2.6.3 Evaluation Criteria and Minimum Reporting Requirements. At the conclusion of each chemical cleaning, the initial condition of transmembrane pressure, flow and temperature shall be recorded and the specific flux calculated. The efficacy of chemical cleaning shall be evaluated by the recovery of specific flux.

$$\% \text{ Recovery of Specific Flux} = 100*(Js_{ac} / Js_i)$$

where: Js_{ac} = Specific flux (L/(hr/m2/bar or gfd/psi,) after chemical cleaning at end of run, and
Js_i = Initial specific flux (L/(hr/m2/bar or gfd/psi) at beginning of filtration run.

- Table of percent specific flux recoveries before and after each chemical cleaning shall be presented.

16.2.7 Task 8C: Perform Membrane Integrity Testing

16.2.7.1 Introduction. Monitoring of membrane integrity is necessary to ensure that an adequate barrier is continuously being provided by the membrane material during the challenge testing. Only direct membrane integrity monitoring shall be employed in the bench-scale testing. Examples of direct monitoring methods include, but are not limited to:

- Air pressure decay testing;
- Diffusive air flow testing;
- Water displacement test;
- Bubble test; and
- Sonic wave sensing.

A brief overview of these direct monitoring methods is provided below.

Air Pressure Decay Test (PDT): In this test, the membrane module is pressurized to approximately 15 psi from the feed side. Minimal loss of the held pressure (generally less than 1 psi every five minutes) at the filtrate side indicates a passed test, while a significant decrease of the held pressure indicates a failed test.

Diffusive Air Flow Test: The diffusive air flow test uses the same concept as the air pressure-decay test, but is performed by monitoring the displaced liquid volume due to the leaking air from compromised fiber(s). This test is more sensitive than the air pressure decay test because it is technically easier and more accurate to measure small variations in liquid volume rather than small variations in air pressure.

Water Displacement Test: The water displacement test is similar to the diffusive air flow test with the exception that the volume of water displaced as a result of an integrity breach is measured instead of the flow of air through a breach.

Bubble Test: Bubble testing can identify the fiber or seal location that is compromised in a membrane module. The test is typically performed after the compromised module is identified by a sonic sensor or any other monitoring method. After identifying the compromised fiber, it can be isolated from the module by adding an epoxy glue to its inlet, or by inserting pins of the same diameter as the fiber at the fiber inlet and outlet edges. The module can then be placed back online.

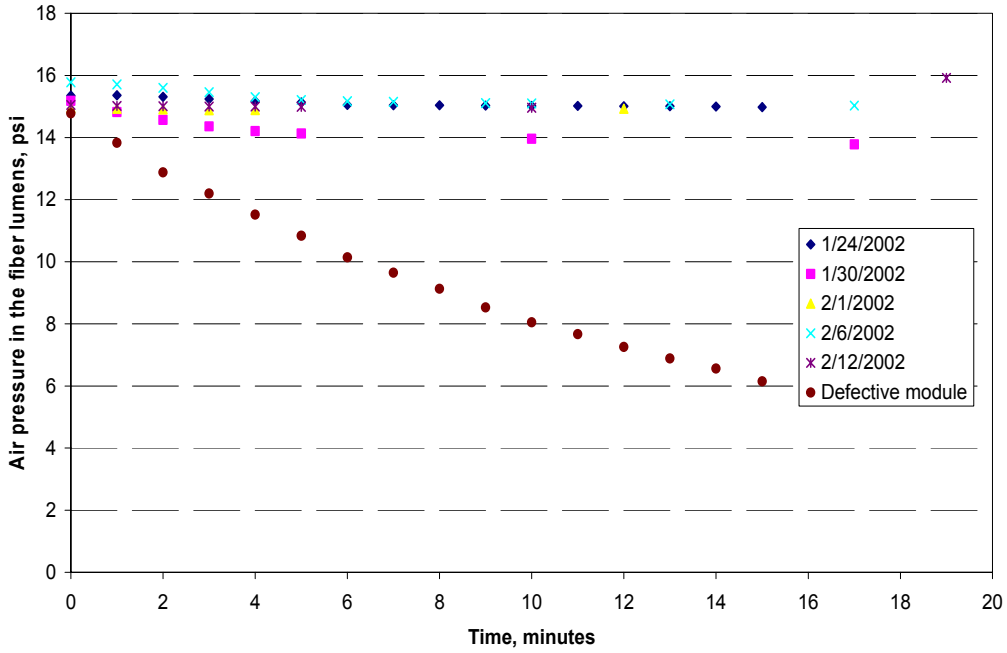
Sonic Wave Sensing: Sonic sensor equipment consists of a sound wave sensor attached to a headphone. The headphones are manually placed at the top, middle, and bottom of the membrane module during the air-pressure decay test to detect any sound waves created by air bubbles leaking through a damaged fiber. The difference in sound between an intact and a compromised membrane may be identified by the pilot operators. Sonic sensing is only a qualitative tool for detecting loss of membrane fiber integrity, and therefore this test must be followed by a more quantitative method for evaluation of membrane integrity.

16.2.7.2 Experimental Objectives. The objective of this task is to demonstrate the methodology to be employed for monitoring membrane integrity at bench scale and to verify integrity of membrane modules.

16.2.7.3 Work Plan. The laboratory testing organization shall clearly describe the most appropriate methods for monitoring of membrane integrity at bench scale. The techniques listed above are intended to serve as examples of direct methods for monitoring membrane integrity. These direct monitoring methods shall provide sensitive evaluation of membrane system integrity. It should be noted that pilot and/or full-scale methods of membrane integrity testing might have to be adapted for bench-scale applicability. Further, the bench-scale integrity monitoring does not replace integrity testing in the field. If the membrane module is shown to be compromised by integrity testing, it shall be discarded and another module shall be provided as a replacement.

Integrity testing shall be performed before and after challenge testing of each module. Since pressure decay tests (PDTs) are often used to measure membrane integrity, an example of adapting pilot integrity methodology to bench scale is described below.

PDTs are performed on each module before and after all challenge testing is completed for that module to assure the membrane module being evaluated is not compromised. To perform the test, the drain line is opened and the membrane fibers are emptied of feed solution by applying pressure from a nitrogen tank to the inner lumen of the fibers at both ends of the modules (it is important, however, to keep the membrane fibers wetted). Nitrogen air feed pressure is set at a pressure recommended by the manufacturer, after which the pressure feed line and drain line is closed. Then, the pressures at the inlet and outlet of the modules are monitored and recorded at intervals of not less than one per minute for a period recommended by the manufacturer. If the module is intact, only a small decrease in pressure is observed (usually less than 1% over a period of 15 minutes). If the membrane material or module is compromised, the PDT will show a substantial decrease of pressure over time. Figure 6 shows PDT data on both intact and compromised modules using a Low-Pressure Membrane Testing Unit.



Pressure Decay Test performed on a 10-fiber, 30-inch long membrane module

Figure 5

16.2.7.4 Evaluation Criteria and Minimum Reporting Requirements.

- Table of membrane integrity results before and after challenge testing, and
- Where appropriate for the selected integrity methodology, a temporal graph of integrity test results conducted before and after challenge testing.

16.2.8 Task 8D: Conduct Microbial Challenge Experiments

16.2.8.1 Introduction. In this task, the effectiveness of membrane materials for microbial removal shall be evaluated by use of microbial challenge studies.

16.2.8.2 Experimental Objectives. The objective of this task is to characterize the low-pressure membranes in terms of microbial removal.

16.2.8.3 Work Plan. The laboratory testing organization shall conduct the microbial seeding studies as described in the sections below.

Organisms Employed for Bench-Scale Challenge Experiments. Table 7 presents the different microorganisms that may be employed for the bench-scale microbial challenge studies. One protozoan oocyst, two bacteria and four viruses can be used for the challenge studies. These organisms were chosen to provide a wide range in types and sizes of microorganisms to create a microbial removal profile for the low-pressure membrane being challenged. The list of microorganisms in Table 7 is not a complete list and other microorganisms may be proposed for use, as circumstances require.

Table 7. Microorganisms for Microbial Challenges of Low-Pressure Membranes*

Type of Microorganism	Microorganism	Approximate size, microns
Protozoa	*Cryptosporidium parvum*	3-5
Bacteria	*Escherichia coli*	1-5
	Pseudomonas diminuta	0.6 –1
Virus	MS2 bacteriophage	0.027
	PRD1 bacteriophage	0.070
	hepatitis A virus	0.025
	calicivirus	0.025

* The list of microorganisms in Table 7 is not a complete list and other microorganisms may be proposed for use as circumstances require.

It is recognized that, in many cases, it may not be possible to employ viable protozoan cysts and oocysts for challenge studies, depending upon the laboratory where the work is being performed. In such a case, the organisms shall be heat-fixed. Organism stocks received from appropriate suppliers shall be stored under refrigeration in the dark at 4^{o}C or frozen (viruses only) with appropriate preservatives until use in the challenge studies. Methods for propagation and enumeration of Table 7 organisms are described or referenced in Appendix 2B. Surrogates may only be used in the bench scale challenge tests in addition to chosen microorganisms to establish a correlation at bench scale or only when peer-reviewed studies and proven methodologies have shown the relationship between surrogates and target microorganisms.

Disinfection of Experimental System. Before performing microbial challenge experiments, the membrane module and tubing associate with the bench-scale low-pressure membrane testing unit shall be disinfected using a free chlorine solution (or other appropriate biocidal agent), which is prepared in a pressurized feed tank. The concentration of the chlorine will be as recommended by the manufacturer. The pressure in the tank shall be set at 15 psi and the membrane unit shall be operated in a backwash mode.

The membrane module and associated tubing shall be backwashed for a minimum of three hydraulic cycles with the disinfecting solution. This module and associated tubing shall then be rinsed with a 3-molar excess sodium thiosulfate solution (or other appropriate chemical) to assure any residual chlorine is quenched. The membrane module shall then be rinsed in backwash mode at 15 psi for an additional three hydraulic cycles with a 0.1 mM phosphate buffer (pH 7.0).

16.2.8.4 Microbial Challenge Experiments. The microbial challenge experiments shall be conducted under the operating conditions in which the microorganisms would be most likely to penetrate the membrane. These conditions shall include the operational flux specified by the manufacturer for their membrane using a 0.1 mM phosphate buffer solution prepared in deionized water. All challenge testing shall be conducted as batch seeding tests under direct flow hydraulic conditions. The challenge testing shall be conducted for all organisms simultaneously, i.e., all organisms shall be seeded into the feed water prior to conducting the testing. Only organisms that do not cross react should be employed. Further, tests shall be conducted to detect and quantify any microbial adsorption that occurs onto the non-membrane parts of the Low-Pressure Membrane Testing Unit. This may be accomplished by conducting a microbial challenge control test with a module that does not contain potted membranes.

For each module tested, four samples shall be collected: two discrete seeded feed tank samples (at the beginning and at end of the each test) and two discrete filtrate samples (samples may be collected sequentially, one right after the other). Thus, for the three modules evaluated, a total of 12 samples shall be collected.

Feed water to which microorganisms shall be added shall consist of a 0.1 M phosphate buffer (pH 7.0) prepared from sterile, deionized laboratory water. To check the quality of the water, measurements of pH, turbidity, particle counts, and conductivity shall be made and recorded before the seeding of any organisms. Additionally, the concentration of TOC shall be less than 0.2 mg/L. Feed water turbidity shall not exceed 0.1 NTU. Total particle counts in the 2 – 50 μm size range shall not exceed 25 per mL. Methods for these analyses are described in Appendix 2B.

The feed suspension of microorganisms shall be prepared by adding the concentrated stock suspension(s) of organisms into the feed water reservoir. For organisms that are propagated at very high titers (for MS2 and PRD1, the initial stock densities are approximately 10^{11} - 10^{12} plaque forming units/mL), one or more dilutions shall be made before adding the organisms to the feed water tank. This tank shall be completely mixed during preparation of the seeded feed water. Sufficient volume of stock suspension shall be created to sustain membrane operation for a minimum of eight hydraulic retention times per membrane module per experimental challenge test. After the addition of challenge organism(s) to the feed water tank and before the initiation of filtration, one discrete sample shall be collected from the feed water tank to establish the initial titer of the microorganisms. Each sample shall consist of collecting 35 mL of filtrate in a sterile, 50 mL polypropylene centrifuge tube (polypropylene is employed to avoid adsorption of the microorganisms onto the walls of tube). For the protozoan challenge tests, the final seeding concentration in the feed water tank shall be high enough to provide a microbial removal sensitivity limit of at least four log. For the bacterial and viral challenge tests, the final seeding concentration in the feed water tank shall also be high enough to provide a microbial removal sensitivity limit of at least 5

log. Detection limits for microorganisms used in challenge testing shall be noted in the QA/QC plan.

After collecting feed water samples, the membrane shall be operated under the hydraulic conditions (pressure and filtrate flux) established under Task 8A. The feed suspension of microorganisms shall be filtered under these conditions for a total of five hydraulic residence times to achieve steady state. At the end of this period, two discrete, consecutive samples shall be collected from the feed tank. Each sample shall consist of collecting 35 mL of filtrate in a sterile, 50 mL polypropylene centrifuge tube. At the conclusion of testing each module, a second sample shall be collected from the feed water tank. All samples shall be stored at 4°C immediately after collection. The $\log_{10}$ mean values of the "before" and "after" feed water tank microbial densities shall be used when calculating microbial removal efficacies.

Before beginning the testing of the next previously-conditioned membrane module, the module and tubing shall be backwashed with 50 mg/L of free chorine (or other appropriate biocidal agent) for five hydraulic cycles. The membrane shall then be rinsed with a 3-molar excess sodium thiosulfate solution (or other appropriate chemical) buffer and phosphate buffer as described above. After this procedure, the next test shall be initiated. At the end of each day, the microbial samples shall be shipped via overnight express for enumeration, if not enumerated on site.

16.2.8.5 Operational Data Collection. Operational data are collected under Task 8A.

16.2.8.6 Evaluation Criteria and Minimum Reporting Requirements.

- Table of water quality data: pH, turbidity, particle counts, and conductivity;
- Table of feed water and filtrate levels for all organisms; and
- Bar chart of log removal of microorganisms.

16.2.9 Task 8E: Execute Data Handling Protocol

16.2.9.1 Introduction. The data management system used in the bench-scale membrane characterization shall involve the use of computer spreadsheets and manual recording of operational parameters for the Low-Pressure Membrane Test Unit.

16.2.9.2 Experimental Objectives. The objective of this task is to establish a structure for the recording and transmission of laboratory testing data.

16.2.9.3 Work Plan. The following protocol has been developed for data handling and data verification by the laboratory testing organization. Specific parcels of the computer databases for operational and water quality parameters shall be entered by manual importation into Excel (or similar spreadsheet software). Backup of the computer databases to diskette, compact disk, magnetic tape or other archival format shall be performed at the end of each day.

Measurements shall be recorded on specially prepared data log sheets as appropriate. A laboratory notebook shall be used to record all data, calculations and other pertinent

information not included in the data log sheets. The laboratory notebook shall provide carbon copies of each page. The original notebooks shall be stored in the laboratory.

The database for the project shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets shall be entered into the appropriate spreadsheet. All recorded calculations shall also be checked at this time. Following data entry, the spreadsheet shall be printed out and the printout shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard copies and corrected on the screen, and then a corrected version of the spreadsheet shall be printed out. Each step of the verification process shall be initialed by the bench testing operator, technician or engineer performing the entry or verification step.

The testing of each membrane module shall be assigned a run number that will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories, if any, shall be received and reviewed by the laboratory staff conducting the studies. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

17.0 TASK 9: RAW WATER PRETREATMENT (OPTIONAL)

17.1 Introduction

In most membrane systems employed for microbial and particle removal, there are usually no chemicals added to the raw water before filtration. However, some manufacturers may wish to be verified for a pretreatment technique that may not be considered a necessary process of the membrane technology for microbiological and particulate removal. As such, pretreatment can be employed to extend membrane operational time or remove selected contaminants. For example, some membranes are capable of absolute removal of microorganisms, but provide little or no removal of DBP precursors. Addition of a coagulant or adsorbent to the raw water may enhance the removal of these precursors.

Verification of optional or separable pretreatment techniques shall constitute an optional task in the verification testing of membrane equipment. This task shall be conducted for an additional month of testing and shall be considered a discretionary supplement to the verification test. In cases where a pretreatment technique is considered an integral or inseparable part of the function of the membrane system, no additional testing of system pretreatment capabilities would be necessary.

17.2 Experimental Objectives

The objectives of this task are to demonstrate membrane performance following a selected pretreatment technique and determine the efficacy of pretreatment for the membrane equipment tested, based upon the manufacturer's treatment goals. For the purposes of this microbiological and particulate contaminant removal TSTP, membrane operation and particulate removal shall be monitored as described in the analytical schedule below. For additional monitoring for removal of selected contaminants, however, the appropriate ETV protocols and TSTPs should be consulted. For

example, if the optional pretreatment selected is designed to achieve removal of precursors to DBPs, the ETV protocol and TSTP for removal precursors to DBPs should be consulted and the analytical schedule followed as a demonstration of equipment performance.

17.3 Work Plan

The focus of this task is to determine the relative rates of flux decline and performance capabilities of the membranes as a function of the selected pretreatment process. Appropriate pretreatment techniques shall be specified by the FTO.

17.4 Analytical Schedule

The pretreatment testing schedule shall be determined by the FTO. However, each pretreatment technique should be tested for a minimum of one month, preferably during the month immediately following the required month of testing for Tasks 1 through 3.

17.4.1 Raw, Pretreated Feed and Filtrate Water Characterization

For this TSTP addressing removal of microbiological and particulate contaminants, monitoring shall be conducted to provide a baseline of the solids removal capabilities of the pretreatment and membrane system. At the beginning of each membrane testing period at a single set of operating conditions (and thereafter with indicated frequency), the raw water, the pretreated feed water and the filtrate water shall be characterized by measurement of the following water quality parameters (as indicated in Table 3):

- Alkalinity (monthly);
- Hardness (monthly);
- TSS (once/two weeks);
- TDS (once/two weeks);
- TOC (monthly*);
- $UV_{254\ nm}$ absorbance (monthly*);
- TC and HPC bacteria (weekly);
- Temperature (daily, raw and pretreated feed only);
- pH (twice per week*);
- Filtrate water turbidity and particle concentrations (daily); and
- Raw water and pretreated feed water turbidity and particle concentrations (daily).

*Note: more frequent monitoring may be performed at the discretion of the manufacturer or FTO.

Additional monitoring may be required for characterization of the raw, pretreated feed and filtrate waters, in the case that protocols and TSTPs for other selected contaminants are employed for demonstration of pretreatment removal capabilities.

17.4.2 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during each period of membrane testing, as required in Table 3. For verification of particulate removal, turbidity and particle concentrations in filtrate waters shall be monitored continuously using either batch or in-line

analytical instruments. Grab samples of raw waters and pretreated feed waters shall be measured by the FTO daily for temperature, turbidity and particle concentrations using bench-top analytical instruments. The specific particle size ranges to be monitored by both in-line and bench-top analytical instruments during the verification testing are indicated in Task 7, the QA/QC section.

TSS shall be monitored every other week and results of this analysis will be used to construct a mass balance of suspended solids through the membrane system. Monitoring of water quality characteristics such as TOC and UV_{254} absorbance shall be performed on a monthly basis to provide a general background on the source water character and quality for each testing period. Additional sampling and data collection may be performed at the discretion of the FTO. Sample collection frequency and protocol shall be defined by the FTO in the PSTP.

On a weekly basis, samples of raw water, pretreated feed water and filtrate shall be collected for analysis of indigenous bacterial densities including: TC and HPC. Collected samples shall be placed in a cooler with blue ice to be shipped with an internal cooler temperature of approximately 2-8°C to the state-certified or third party- or EPA-accredited analytical laboratory. Samples shall be processed for analysis by a laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the EPA within 24 hours of collection. The laboratory shall then keep the samples at a temperature of approximately 2-8°C until initiation of analysis. TC densities will be reported as most probable number per 100 mL (MPN/100 mL) and HPC densities will be reported as colony forming units per milliliter (cfu/mL).

17.4.3 Feed Water Quality Limitations

The characteristics of raw waters and pretreated feed waters encountered during the one-month testing period shall be explicitly stated in reporting the membrane flux and recovery data. Accurate reporting of such feed water characteristics as temperature, turbidity, TSS, pH, alkalinity and hardness is critical for the verification testing program, as these parameters can substantially influence membrane performance on a seasonal basis.

17.5 Evaluation Criteria and Minimum Reporting Requirements

- Transmembrane pressure (P_{tm}):
  - Plot graph of transmembrane pressure over time for each 30 day period of operation.

- Rate of specific flux decline:
  - Plot graph of specific flux normalized to 20 degrees C over time for each 30 day period of operation.

- Cleaning frequency:
  - Provide table of intervals between chemical cleaning episodes during each 30 day period of operation.

- Cleaning efficacy:
  - Provide table of cleaning efficacy indicators for chemical cleaning procedures performed during each 30 day period of operation.

- Flux recovery:
  - Provide table of post cleaning flux recoveries during each 30 day period of operation.

- Turbidity, particle concentrations and particle removal:
  - Plot graph of raw water, pretreated feed, and filtrate turbidity over time during each 30 day period of operation;
  - Plot graph of raw water, pretreated feed, and filtrate particle concentrations over time during each 30 day period of operation;
  - Plot graph of log removal of particles between raw water, pretreated feed, and filtrate water at one-day intervals over time during each 30 day period of operation; and
  - Perform mass balance calculations of TSS through the membrane system and calculate concentrations of TSS in the backwash waste water. Calculated values shall be compared with actual measured TSS concentrations in backwash waste. (These backwash TSS concentrations may be an important consideration for residuals disposal.).

- Water quality and removal goals specified by the manufacturer:
  - Provide raw water, pretreated feed, and filtrate levels for TOC and UV_{254} absorbance in tabular form for each 30 day period of operation, and
  - Provide raw water, pretreated feed, and filtrate concentrations of any selected water quality parameters in tabular form for each 30 day period of operation.

- Removal of indigenous bacteria (TC and HPC):
  - Provide raw water, pretreated feed, and filtrate levels for TC and HPC bacteria in tabular form for each 30 day period of operation, and
  - Provide values for TC and HPC log removal in tabular form for each 30 day period of operation.

18.0 OPERATION AND MAINTENANCE

The FTO shall obtain the manufacturer-supplied O&M manual(s) to evaluate the instructions and procedures for their applicability during the verification testing period. Below are recommendations for criteria to evaluate O&M manuals for membrane filtration equipment that are designed to achieve removal of microbiological and particulate contaminants.

18.1 Maintenance

The manufacturer shall provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- Pumps
- Valves
- Pressure gauges
- Backwash controls;
- Flow meters;
- Air compressors;
- Chemical feeder systems;
- Mixers;

- Motors;
- Instruments, such as streaming current monitors or turbidimeters; and
- Water meters, if provided.

The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- Tanks and basins;
- In-line static mixers; and
- Tubing and hoses.

18.2 Operation

The manufacturer should provide readily understood recommendations for procedures related to proper operation of the equipment. Among the operating aspects that should be discussed are:

Filtration:
- Control of feed flow to the membrane system;
- Measurement of inlet/outlet pressures and filtrate flows;
- Measurement of transmembrane pressure changes during filter run; and
- Feed flow control in response to temperature changes.

Membrane backwashing:
- Programming automated frequency;
- Proper backwash venting and disposal;
- Appropriate backwash rate (if applicable); and
- Monitoring during return of filter to service.

Chemical cleaning:
- Selection of proper chemical washing sequence;
- Proper procedures for dilution of chemicals;
- Monitoring of pH through chemical cleaning cycle;
- Rinsing of membrane system following chemical clean; and
- Return of filter to service.

Chemical feeders (in the case that chemical pretreatment is applied):
- Calibration check;
- Settings and adjustments (how they should be made); and
- Dilution of chemicals and polymers (proper procedures).

Monitoring and observing operation:
- Observation of feed water or pretreated water turbidity;
- Observation of transmembrane pressure increase between backwashes;
- Filtered water turbidity;
- Filter head loss; and
- What to do if turbidity breakthrough occurs.

The manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- No raw water (feed water) flow to plant;
- Can't control rate of flow of water through equipment;
- Valving configuration for direct flow and cross-flow operation modes;
- Poor raw water quality (raw water quality falls outside the performance range of the equipment);
- Poor filtrate quality;
- Failed membrane test;
- Low pump feed pressure;
- Automatic operation (if provided) not functioning;
- Filtered water turbidity too high;
- Head loss builds up excessively rapidly;
- Reduced filtrate flux;
- Machine will not start and "Power On" indicator off;
- Machine will not start and "Power On" indicator on;
- Pump cavitation;
- Valve stuck or won't operate; and
- No electric power.

It is also recommended that the manufacturer add a toll free number to the O&M manual for technical assistance on operation and maintenance of the equipment.

The following are recommendations regarding operability aspects of systems that are designed to achieve removal of microbiological and particulate contaminants. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of equipment testing when the testing is done under this TSTP.

During verification testing and during compilation of historical equipment operating data, attention shall be given to equipment operability aspects. Among the factors that should be considered are:

- Fluctuation of flow rates and pressures through membrane unit including the time interval at which resetting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?).

- Presence of devices to aid the operator with flow control adjustment and chemical dosage selection:
  - Are influent and filtered water continuous turbidimeters provided;
  - Are continuous particle counter provided on membrane filtered water; and/or
  - Can backwash be done automatically?

- If automatic backwash provided, could it be initiated by:
  - Reaching a set value for head loss;
  - Reaching a set value for filtered water turbidity; and/or
  - A preset automatic timer?

- Does remote notification to operator occur when backwash happens?

- Can operator observe backwash?

- Does plant have multiple feed points for chemicals:
  - For pH adjustment;
  - For coagulant chemical feed; and/or
  - For antiscalant addition?

- Is transmembrane pressure measurement provided?

- Is rate of flow of raw water measured?

- Is chemical feed paced with raw water flow?

- Is backwash rate of flow measured and variable?

- Is backwash duration (time) variable?

Both the reviews of historical data and the reports on verification testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Tasks 1 & 2 of this TSTP addressing the removal of microbiological and particulate contaminants.

19.0 REFERENCES

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APPENDIX 2A

STATE-SPECIFIC VERIFICATION TESTING REQUIREMENTS

Ohio:

- It would be informative to determine maximum membrane pore size at the end of the testing (i.e., end of month 11) as well as at the beginning (month 1).

- Alkalinity and hardness measurement should be increased to daily.

Alaska:

- The task of reporting the membrane pore size will be required.

Missouri:

- The task of reporting the membrane pore size will be required.

APPENDIX 2B:
QUALITY ASSURANCE/QUALITY CONTROL

Introduction

Quality assurance and quality control (QA/QC) of the operation of the membrane equipment and the measured water quality parameters shall be maintained during the laboratory testing program.

Operational and Low-Pressure Membrane Testing Unit QA/QC

Before the testing of each manufacturer's modules, on-line pressure gauges shall be checked with secondary gauges to confirm that the readout matches the actual measurement. Unit tubing and connections shall be inspected weekly to check that they are in good condition. Replacement of these materials shall be made as necessary.

Analytical Methods

The analytical methods utilized in this study for feed waters are described in the section below.

pH. Analyses for pH shall be performed according to *Standard Method* 4500-H^+. A 3-point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual.

Temperature. Readings for temperature shall be conducted in accordance with *Standard Method* 2550. The thermometer shall have a scale marked for every 0.1°C, as a minimum, and shall be calibrated biweekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of –1°C to +51°C, subdivided in 0.1°C increments, would be appropriate for this work.)

Turbidity Analysis. Turbidity analyses shall be performed according to *Standard Method* 2130 or EPA Method 180.1 using a bench-top turbidimeter. All glassware used for turbidity measurements shall be cleaned and handled using lint-free tissues to prevent scratching. Sample vials shall be stored inverted to prevent deposits from forming on the bottom surface of the cell. Grab samples shall be analyzed using a bench-top turbidimeter. Information on calibration, verification of calibration, sampling and analysis can be found in the ETV Protocol for Equipment Testing for Physical Removal of Microbiological and Particulate Contaminants (NSF/USEPA, 2002).

Particle Counting. Bench-top particle counters shall be used to measure particle concentrations in the feed water. Laser light scattering or light blocking instruments are recommended for particle counting; however, other types of counters such as Coulter counters or Elzone counters may be considered.

The following particle size ranges shall be monitored by bench-top analytical instruments during the membrane characterization testing:

- 2-3 μm;
- 3-5 μm;
- 5-7 μm;

- 7-10 μm;
- 10-15 μm; and
- >15 μm.

Information on calibration, verification of calibration, maintenance of the particle counters, particle free water, sampling and analysis can be found in the *ETV Protocol for Equipment Testing for Physical Removal of Microbiological and Particulate Contaminants* (NSF/USEPA, 2002).

Conductivity. This parameter shall be measured according to *Standard Method* 2510B (1998).

Total Organic Carbon (TOC) /Dissolved Organic Carbon (DOC). TOC/DOC shall be analyzed according to *Standard Method* 5310B or 5310C (1998).

Chlorine Preparation for Membrane Cleaning. The stock solution shall be prepared by adding an estimated volume of 6% reagent-grade NaOCl into a 500-mL, chlorine demand-free bottle containing an estimated amount of organic-free water. The concentration of the chlorine solution will be as recommended by the manufacturer. Refer to *Standard Method* 4500-Cl F for the preparation method of DPD indicator, FAS standard and buffer solution. Residual free chlorine measurements will be conducted according to *Standard Methods* 4500-Cl G. DPD Colorimetric Method.

Bacteriophages. Bacteriophages MS2 and PRD1 shall be enumerated according to National Water Research Institute and American Water Works Association Research Foundation, 2000. Because of the importance of this organism in characterizing the membrane at bench scale, detailed methods for MS2 are provided below and shall be followed.

MS2 bacteriophage Soft Agar Overlay Method and MS2 Stock Preparation. The bacteriophage MS2 – ATCC 15597-B1 shall be employed in all studies. The *Escherichia coli* C-3000 – ATCC 15597 shall be employed as the host bacterium, with the bacterial growth media being tryptic soy broth (TSB) – DIFCO 0370-15-5, or the equivalent.

Tryptic Soy Agar (bottom agar petri plates 100 x 15mm) Preparation. The media is rehydrated according to label directions. A magnetic stir bar is placed into the dehydration flask, and the media is brought to a near boil to dissolve the agar. The flask and contents are then sterilized by autoclaving for 15 minutes after which it is cooled in a water bath to between 45-50^{o}C. Plates are poured using approximately 12–15 mL per plate. Enough agar is added to cover about 2/3 of the area of the plate. After pouring one plate, the lid is replaced on the dish and gently swirled so that the agar covers the entire bottom of the plate. Plates are allowed to remain motionless until the agar hardens (usually 10-15 minutes). Plates are stored at 4^{o}C up to 30 days.

Tryptic Soy Agar Overlay Tubes. The media is rehydrated according to label directions. A magnetic stir bar is placed into the rehydration flask, and the media is brought to a near boil to dissolve the agar. The media is sterilized for 15 minutes and then pipeted aseptically into 15 mL tubes (3mL per tube) or pipeted into the tubes (3 mL per tube), which are then capped loosely and sterilized for 15 minutes. The caps are tightened after cooling. Overlay tubes are stored at 4^{o}C for 30 days.

Preparation of High-Titer MS2 Bacteriophage. To propagate the MS2 bacteriophage, a bacterial host slant of *E. coli* (ATCC #15597) is washed with 3 mL of sterile TSB. The total 3 mL is then transferred to a 1-liter flask containing 200 mL of sterile TSB and incubated at 37^{0}C for approximately 3 hours. At this time, the flask is removed from the incubator and 2 mL of

bacteriophage stock (ATCC #15597-B1) is added and then the flask is placed back in the incubator for an additional four hours. Then, 0.02 g of lysozyme and 6 mL of 0.2 M sterile EDTA are added to the flask which is shaken for an additional 30 minutes. The bacteriophage/bacteria suspension is poured into 4-50mL centrifuge tubes and centrifuged at 4,000 times gravity for 15 minutes.

During preparation of high titer MS2 bacteriophage stocks, there is a potential for aggregate formation. To reduce aggregates, the MS2 stock is filtered through sequentially smaller (0.45 micron, 0.22 micron and 0.1 micron), low protein-binding filters. To reduce MS2 binding to the filter, each filter is pretreated by filtering 10 mL of 0.1% Tween 80 followed by 10 mL reagent grade non-chlorinated water. MS2 stock preparations are filtered through these pretreated filters with careful attention focused on amount of pressure/vacuum applied to prevent membrane filter failure. Multiple filters may be necessary to filter the entire MS2 stock solution.

The bacteriophage stock is then titered to determine its concentration and stored at 4^{o}C for up to four weeks.

Preparation of Host Culture. The host culture is started the day before the assay is to be performed. Using a sterile swab, a small amount of *E. coli* host (ATCC 15597) is removed from an agar slant and placed into a sterile tube containing 3 mL of tryptic soy broth and grown overnight at 37^{o}C for 24 hours. The next day, 1 mL of the overnight culture is pipeted into 50 mL of tryptic soy broth in a 250 mL Erlenmeyer flask or the equivalent. The culture is then placed in a 37^{o}C incubator for four hours, after which it is removed from incubator and place on ice until used.

Soft Agar Overlay Method for Bacteriophage. Bacteriophage in bench-scale low-pressure membrane samples are enumerated by the addition of the sample to soft or overlay agar along with a liquid culture of bacteria (host) in the log phase of growth. Overlay tubes are melted in a boiling water bath or autoclaved for five minutes and place in a 49^{o}C water bath until used. The bottom of the petri plates are labeled with the identification of sample to be analyzed. Then 0.1 – 1 mL of the 4-hour host culture (which is in log phase of growth) is pipeted into a prewarmed overlay tube along with 0.1 –1 mL of the sample to be analyzed. The tube is mixed by rapidly rolling between the analyst's palms and poured onto a TSA plate. The sample is spread evenly over the surface of the plate by gently and quickly swirling the plate. The plate, which solidifies within 30 seconds, is then inverted and incubated at 37^{o}C for 24 hours +/- 2 hours. The sample is then incubated for 24 hours. During the incubation time, the host bacteria forms a confluent lawn over the surface of the petri plate. The petri plate is incubated at 37^{o}C for 24 hours. During the incubation period, the phage particles that are present in the sample attach to and infiltrate the bacterial host cells. The bateriophages replicate within the bacterial cells and reach a concentration that lyse (burst) the bacterium. The destruction of the bacterial cells that make up the confluent lawn result in clear areas known as plaques. The concentration of bacteriophage originally present in the sample are determined by visually counting the clear areas, which are reported number of plaque forming units per mL (PFU/mL).

Giardia sp.* and *Cryptosporidium sp. These organisms shall be enumerated according to U.S. Environmental Protection Agency Method 1623 (1999).

Pseudomonas diminuta. This organism shall be enumerated according to ASTM Method F838-83 (1993).

Escherichia coli. This organism shall be enumerated according APHA, AWWA, and WEF (1999).

APPENDIX 2C:
MATERIALS EMPLOYED FOR FABRICATION OF BENCH SCALE LOW-PRESSURE MEMBRANE TEST UNIT

(Note: if needed, contact NSF for potential source of materials.)

- Pressure vessel with vacuum closure (2-gallon volumes);
- Glass-filled nylon instant tube ("plug and play") fitting, male pipe adapters ¼'', ¼'';
- Glass-filled nylon instant tube ("plug and play") fitting, male 90 elbow pipe adapters ¼'', ¼'';
- Glass-filled nylon instant tube ("plug and play") fitting, male branch tee pipe adapters ¼'', ¼'', ¼'';
- Glass-filled nylon instant tube ("plug and play") fitting, male run tee pipe adapters ¼'', ¼'' ¼'';
- Glass-filled nylon instant tube ("plug and play") fitting, coupling ¼'', ref 5779k14;
- Glass-filled nylon instant tube ("plug and play") fitting, 90 elbow ¼'', ref 5779k24;
- Glass-filled nylon instant tube ("plug and play") fitting, tee ¼'', ref 5779k34;
- Cement: All-purpose cement for PVC, ABS, CPVC and reference 30821;
- Nylon tubing: named "Nylon 6 tubing" and order in ¼'' OD, ref 5173K9;
- PVC threaded pipe fitting – schedule 80 – dark gray, reducing hex bushing, NPT male ¾'' x NPT female ½'', ref 4596k414;
- Miniature chrome-plated brass ball valves, female ¼'', female ¼'', wedge handle, ref 4912k47; and
- Teflon thread sealant tape, ½'' width, ref 4591k12.

CHAPTER 3

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN
COAGULATION AND FILTRATION FOR THE REMOVAL OF MICROBIOLOGICAL AND PARTICULATE CONTAMINANTS

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for evaluation of water treatment equipment utilizing chemical coagulation and filtration processes. This Testing Plan is to be used as a guide in the development of the Product-Specific Test Plan for testing coagulation and filtration equipment, within the structure provided by the Document, "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies." This Equipment Verification Testing Plan is applicable only to granular media filtration processes that rely upon chemical coagulation to effectively condition the feed water for effective filtration.

In order to participate in the equipment verification process for coagulation and filtration, the equipment Manufacturer shall employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of Product-Specific Test Plan. The Procedures shall generally follow those Tasks related to Verification Testing that are outlined herein, with changes and modification made for adaptations to specific water treatment equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

- Introduction;
- Objectives;
- Work Plan;
- Analytical Schedule;
- Evaluation Criteria.

Each Product-Specific Test Plan shall include Tasks 1 through 6.

2.0 INTRODUCTION

Various types of water treatment equipment employing processes of coagulation and filtration are used for a wide number of applications, including removal of turbidity from surface waters; removal of bacteria, viruses, *Giardia* and *Cryptosporidium;* removal of algae, and removal of color and other natural organic matter from surface waters. Some equipment process trains use only chemical coagulation, mixing, and granular media filtration. Others employ a solids separation or clarification step between coagulation and filtration. Clarification processes may include one of the following:

- sedimentation;
- sedimentation aided by tubes or plates;
- downflow contact clarification;
- upflow contact clarification;
- dissolved air flotation (DAF).

This Equipment Verification Testing Plan is applicable to the testing of water treatment equipment utilizing a coagulation and filtration process train which may include a clarification step before filtration. Two phases of testing are discussed. The first phase is Initial Operations, which consists of a series of tests that will be used by the Manufacturer to determine the optimum chemical pretreatment scheme at a specific geographical location. The second phase is Verification Testing, which will evaluate performance of the equipment under different raw water quality conditions.

Verification Testing will be done for relatively short time intervals during one or more time periods when the source water or feed water quality is appropriate for testing the full range of water quality conditions that need to be evaluated. This will include cold water and water having high and low turbidity.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analytical work to be carried out as a part of this Verification Testing Plan will be contracted with a state-certified or third party- or EPA-accredited laboratory.

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the recommended tasks that may be included in Initial Operations and of the required and optional tasks to be included in the coagulation and filtration Verification Testing program.

4.1 Task A: Characterization of Feed Water

The objective of this recommended Initial Operations task is to obtain a chemical, biological and physical characterization of the feed water. A brief description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization.

4.2 Task B: Initial Tests Runs

During Initial Operations, a Manufacturer may want to evaluate equipment operation and determine the chemical dosages and other pretreatment conditions that result in effective treatment of the feed water. This is a recommended Initial Operations task.

4.3 Task 1: Verification Testing Runs

Water treatment equipment shall be operated for at least 320 hours during each testing period to collect data on equipment performance and water quality for purposes of performance verification.

4.4 Task 2: Feed Water and Finished Water Quality

During each day of Verification Testing, feed water and treated water samples shall be collected, and appropriate sample analysis shall be undertaken.

4.5 Task 3: Operating Conditions and Treatment Equipment Performance

During each day of Verification Testing, operating conditions and performance of the water treatment equipment shall be documented. Operating conditions include pretreatment chemistry for coagulation, a listing of treatment processes used, and their operating conditions. Equipment performance includes rate of filter head loss gain, frequency and duration of filter washing, and need for cleaning of pretreatment clarifiers.

4.6 Task 4: Microbiological Contaminant Removal

The objective of this task is to estimate the capability of coagulation and filtration equipment to remove microorganisms by measuring turbidity and particle counts in feed water and filtered water, and to evaluate removal of microbiological contaminants during Verification Testing by measuring removal of microorganisms naturally present in the feed water or by measuring the removal of seeded microorganisms such as algae, bacteria, coliphage, or protozoa, or a combination of those types of microorganisms.

4.7 Task 5: Data Management

The objective of this task is to establish an effective field protocol for data management at the field operations site and for data transmission between the Testing Organization and the NSF for data obtained during the Verification Testing.

4.8 Task 6: QA/QC

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during coagulation and filtration equipment Verification Testing.

5.0 TESTING PERIODS

The required tasks in the Verification Testing Plan (Tasks 1 through 6) are designed to be carried out over one or more 320-hour periods, not including mobilization, start-up, and Initial Operations.

A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary to verify the manufacturer's statement of performance capabilities, such as in the treatment of surface water where additional testing during each season may assist in verifying an objective. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's objectives. For example this may include water having high and low turbidity and cold water. Although one testing period satisfies the minimum requirement of the ETV program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined in Initial Operations. Performance and reliability of the equipment shall be tested during verification testing periods at a minimum of 320-hour periods. The purposes of the 320-hour test period are to: 1) provide opportunity for treatment of feed water having variable quality; 2) provide a data base on multiple filter runs from start-up to backwash, so data can be subjected to statistical analysis (Data from multiple runs are needed for rate of head loss accumulation, total water production during a filter run, chemical consumption, and filtered water quality.); and 3) provide data demonstrating repeatability and dependability of the treatment process over time.

A schedule describing the duration and initiation of each of the above tasks is provided in Table 1.

Table 1. Generic Schedule for Verification Testing		
Test Period	Initial Operations, Estimated Time	Verification Testing, Required Time
1 (required)	1 – 6 weeks	320 hours
2 (optional)	1 – 3 weeks	320 hours
3 (optional)	1 – 3 weeks	320 hours
4 (optional)	1 – 3 weeks	320 hours

6.0 DEFINITIONS

Definitions that apply for coagulation and filtration processes and that were given in the Surface Water Treatment Rule, as published in the *Federal Register* on June 29, 1989, are:

6.1 Coagulation: A process using coagulant chemicals and mixing by which colloidal and suspended materials are destabilized and agglomerated into flocs.

6.2 Conventional filtration treatment: A series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particulate removal.

6.3 Direct filtration: A series of processes including coagulation and filtration but excluding sedimentation resulting in substantial particulate removal.

6.4 Filtration: A process for removing particulate matter from water by passage through porous media.

6.5 Flocculation: A process to enhance agglomeration or collection of smaller floc particles into larger, more easily settleable particles through gentle stirring by hydraulic or mechanical means.

6.6 Sedimentation: A process for removal of solids before filtration by gravity or separation.

Other definitions not included in the Surface Water Treatment Rule include:

6.7 Dissolved air flotation: A process in which coagulated, flocculated water is introduced into the bottom of a chamber, along with recycled water containing microscopic air bubbles. The bubbles rise to the water surface, carrying the floc up, while the clarified water leaves the chamber near the bottom.

6.8 Contact clarification: A process in which coagulated water is applied to a bed of coarse granular media. Flow may be downward from the top of the media bed to the bottom, or upward from the bottom of the media bed to the top. The bed of coarse media acts both as a flocculator by causing the division and recombination of flow streams of coagulated water, and as a clarifier, by trapping and removing some of the floc that forms as water flows through the bed. The coarse granular media may consist of natural mineral material or man-made materials such as plastic.

7.0 TASK A: CHARACTERIZATION OF FEED WATER

7.1 Introduction

This Initial Operations task is needed to determine if the chemical, biological and physical characteristics of the feed water are appropriate for the water treatment equipment to be tested.

7.2 Objectives

The objective of this task is to obtain a complete chemical, biological, and physical characterization of the source water or the feed water that will be entering the treatment system being tested.

7.3 Work Plan

This task can be accomplished by using analytical measurements obtained from third party sources (i.e. USGS, USEPA, State Laboratories, Municipal Laboratories). The specific parameters needed to characterize the water will depend on the equipment being tested but information on the following characteristics should be compiled:

- Water Temperature, pH, Turbidity, and Color
- Total Alkalinity, Calcium Hardness, Iron, and Manganese
- Total Coliform, *Bacillus* spores, and Algae
- Data on Aluminum, Total Nitrogen, Total Phosphorus, and Free Ammonia would be informative if such data are available

Sufficient information shall be obtained to illustrate the variations expected to occur in these parameters that will be measured during Verification Testing for a typical annual cycle for the water source. This information will be compiled and shared with NSF so NSF and the Testing Organization can determine the adequacy of the data for use as the basis to make decisions on the testing schedule. Failure to adequately characterize the feed water (source water) could result in testing at a site later deemed inappropriate, so the initial characterization will be important to the success of the testing program.

A brief description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization. The watershed description should include a statement of the approximate size of the watershed, a description of the topography (i.e. flat, gently rolling, hilly, mountainous) and a description of the kinds of human activities that take place (i.e. mining, manufacturing, cities or towns, farming) with special attention to potential sources of pollution that might influence feed water quality. The nature of the water source, such as stream, river, lake, or man-made reservoir, should be described as well.

7.4 Analytical Schedule

In many cases, sufficient water quality data may already exist to permit making a determination of the suitability of a source water for use as feed water in a coagulation and filtration Verification Testing program.

7.5 Evaluation Criteria

Feed water quality will be evaluated in the context of the Manufacturer's statement of performance objectives. The feed water should challenge the capabilities of the equipment but should not be beyond the range of water quality suitable for treatment for the equipment in question.

8.0 TASK B: INITIAL TEST RUNS

8.1 Introduction

During Initial Operations, a Manufacturer may want to evaluate equipment operation and determine the chemical dosages and other pretreatment conditions that result in effective treatment of the feed water. This is a recommended Initial Operations task. An NSF field inspection of equipment operations and sampling and field analysis procedures will be carried out during the initial test runs.

8.2 Objectives

The objective of these test runs is to determine the proper chemical pretreatment scheme for treatment of the feedwater during Verification Testing. The chemical pretreatment requirements may be different for feedwaters from different test sites or for the feedwater from the same site during testing periods when water quality has changed from the quality encountered during an earlier testing period. Therefore, conducting initial test runs is strongly recommended.

8.3 Work Plan

Conducting jar tests often is a cost effective means of developing data on coagulant chemical dosages and pH that give effective coagulation. Use of jar tests is recommended before filtration testing is begun. The American Water Works Association's Manual M37, "Operational Control of Coagulation and Filtration Processes," contains a chapter that describes procedures for using jar tests to optimize coagulation. Exploration of use of both alum and iron as inorganic coagulants may be appropriate. Evaluation of the effect of polymers on coagulation, flocculation, and sedimentation could also be done in jar testing.

After jar tests have identified effective conditions for coagulation, several test runs may be needed to further refine appropriate chemical pretreatment conditions. If use of filter aid polymers is contemplated, they should be evaluated in filter runs rather than in jar tests, because jar tests cannot be used to demonstrate the increase of head loss during a filter run. At the end of these tests, an effective chemical pretreatment scheme should have been defined. During initial operations the filters should be operated for a period of 24 hours, or for filter run times as long as those anticipated during Verification Testing.

Filters will be operated until either terminal headloss is reached or effluent turbidity increases above 0.5 NTU or a value set by the Manufacturer.

8.4 Analytical Schedule

Because these runs are being conducted to define operating conditions for Verification Testing, a strictly defined schedule for sampling and analysis does not need to be followed. Adhering to the

schedule for sampling and analysis to be followed during Verification Testing would be wise, however, so the operator can gain familiarity with the time requirements that will be applicable later on in the test program. Also, during the Initial Operations phase, the NSF will be conducting an initial on-site inspection of field operations, sampling activities, and on-site sample analysis. The sampling and analysis schedule for Verification Testing shall be followed during the on-site inspection.

8.5 Evaluation Criteria

The Manufacturer should evaluate the data produced during the Initial Operations to determine if the water treatment equipment performed so as to meet or exceed expectations based on the statement of performance objectives. If the performance was not as good as the statement of performance objectives, the Manufacturer may wish to conduct more Initial Operations or to cancel the testing program.

Examples of performance objectives that might be included in the statement of performance objectives are presented in Table 2.

Table 2. Examples of Filtration Performance Objectives

Characteristic	Definition	Criteria
Initial Turbidity	Filtered turbidity at 15 minutes into run	0.5 NTU or less
Length of Initial Improvement Period	Time to reach 0.2 NTU	0.5 hour or less.
Length of Initial Improvement Period	Time to reach 0.1 NTU	1.0 hour or less.
Operating Turbidity	Turbidity from matured filter	0.10 NTU or less.
All Turbidity Data	All data taken at equal, periodic time intervals from beginning to end of run	0.5 NTU or less in 95% of all turbidity samples analyzed or in all data from continuous turbidimeter at periodic time intervals
Time to Reach Turbidity Breakthrough	Time to reach turbidity over 0.20 NTU	8 hours minimum.
Time to Reach Terminal Head loss	Time to reach 5 ft increase in head loss	8 hours minimum.
Water Production	Volume of water filtered during a run	5000 gallons per square foot of filter area.

9.0 TASK 1: VERIFICATION TESTING RUNS AND ROUTINE EQUIPMENT OPERATION

9.1 Introduction

Water treatment equipment employing coagulation and filtration shall be operated for Verification Testing purposes, with the approach to coagulation based on the results of the Initial Operations testing.

9.2 Experimental Objectives

The objective of this task is to operate the treatment equipment provided by the Manufacturer and to assess its ability to meet the water quality goals and any other performance characteristics specified by the Manufacturer in the statement of performance objectives.

9.3 Work Plan

9.3.1 Verification Testing Runs

The Verification Testing Runs in this task consist of continued evaluation of the treatment system, using the most successful treatment parameters defined in Initial Operations. One or more Verification Testing periods, each lasting for a minimum of 320 hours (13 full days plus one 8-hour shift), are anticipated for evaluating the performance of a treatment system. Verification Testing should be conducted to treat feed water having a range of quality consistent with the Manufacturer's statement of performance capability for the equipment. Testing of cold water having high turbidity and cold water having low turbidity is recommended. During each testing period, Tasks 1 through 5 shall be conducted simultaneously.

Operation under a wide variety of water quality conditions is recommended because of the differences in water quality that occur over time in many source waters. For coagulation and filtration treatment equipment, factors that can influence treatment performance include:

- cold water, encountered in winter or at high altitudes in mountainous regions of the country
- high turbidity, often occurring in spring, encountered in rivers carrying a high sediment load or in surface waters during periods of high runoff resulting from heavy rains or snowmelt
- algae, which may exhibit blooms on a seasonal basis, such as in summer or fall
- natural organic matter, which may be higher in some waters in the fall
- pH, alkalinity, and hardness, which may vary over time

Among the above-listed factors that can influence coagulation and filtration performance, those that may be most commonly encountered are cold water with high turbidity and cold water with low turbidity. Coagulation and flocculation of water at temperatures of 5^{o}C or lower seems to be especially difficult. It is highly unlikely that all of the above problems would occur in a surface water during a single testing period, and this results in the recommendation for testing during different times of the year or at different locations.

A minimum of three complete filter runs, ended either by turbidity breakthrough or by attaining terminal head loss, shall be performed, even if the time required for testing exceeds the minimum specified time stipulated in this section. If three complete filter runs are attained in less that the minimum time, filter operation must continue until the minimum time for Verification Testing has been fulfilled.

9.3.2 Routine Equipment Operation

If the water treatment equipment is being used for production of potable water, in the time intervals between verification runs, routine operation for water production is anticipated. In this situation, the operating and water quality data collected and furnished to the SDWA primacy agency shall also be supplied to the NSF-qualified Testing Organization.

9.4 Schedule

During Verification Testing, water treatment equipment shall be operated continuously for a minimum of 320 hours with interruptions in filtration as needed for backwashing of the filters or for other necessary equipment operations. Coagulation and filtration treatment equipment shall be operated from start-up until turbidity breakthrough or terminal head loss is attained, at which time the filter shall be washed and operation shall resume. Filter runs shall not be stopped before turbidity breakthrough or terminal head loss except because of equipment failure or power interruption, because data on complete filter runs are needed to fulfill the objectives of Verification Testing. The duration of each filter run and the number of gallons of water produced per square foot of filter area shall be recorded in the operational results.

During routine equipment operation, the water treatment equipment should be operated in a manner appropriate for the needs of the water system.

9.5 Evaluation Criteria

The goal of this task is to operate the equipment for the 320 hour period, including time for filter washing and other necessary operating activities, during Verification Testing. Data shall be provided to substantiate the operation for 320 hours or more.

10.0 TASK 2: TEST RUNS FOR FEEDWATER AND FINISHED WATER QUALITY

10.1 Introduction

Water quality data shall be collected for the feedwater and filtered water as shown in Table 3, during Verification Testing. At a minimum, the required sampling schedule shown in Table 3 shall be observed by the Field Testing Organization. Water quality goals and target removal goals for the water treatment equipment shall be recorded in the Product-Specific Test Plan in the statement of objectives.

10.2 Experimental Objectives

A list of the minimum number of water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 3. The actual

water quality parameters selected for testing shall be stipulated in the Product-Specific Test Plan and shall include all those necessary to permit verification of the statement of performance objectives.

Table 3. Water Quality Sampling and Measurement Schedule	
Sample or Measure For:	Frequency:
Temperature	Daily
pH	Daily
Total alkalinity	Daily
Hardness	Weekly
Total organic carbon	Weekly
UV_{254} absorbance	Weekly
Turbidity	Feed water turbidity collected at least once per 4 hours with grab samples, or continuous monitoring. Filtered water turbidity continuous monitoring. Daily at bench to check continuous turbidimeters
Particle Counts	Feed water particle counts collected at least once per 4 hours with grab samples, or continuous monitoring. Filtered water particle counts continuous monitoring.
Aluminum	Weekly if aluminum salt coagulant used
Iron	Weekly
Manganese	Weekly if present in concentration of 0.05 mg/L or greater
Algae, number and species	Weekly if no algae bloom Daily if algae bloom occurs
True color	Weekly
The schedule for collection of microbiological samples and for additional particle counting is presented in Task 4.	

10.3 Work Plan

The Field Testing Organization will be responsible for establishing the equipment operating parameters, on the basis of the Initial Operations testing. The filter shall be operated continuously until terminal headloss is attained, at which time it shall be backwashed.

Many of the water quality parameters described in this task will be measured on-site by the NSF-qualified Testing Organization (refer to Table 4). Analysis of the remaining water quality parameters will be performed by a state-certified or third party- or EPA-accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field will be described in the Analytical Methods section below and in Table 4. The analytical methods utilized in this study for on-site monitoring of feedwater and filtered water qualities are described in Task 6, Quality Assurance/Quality Control (QA/QC). Where appropriate, the *Standard Methods* reference numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

10.3.1 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during each period of filtration testing, as noted in this section. Additional sampling and data collection may be performed at the discretion of the Manufacturer. Sample collection frequency and protocol shall be defined in the Product-Specific Test Plan.

In the case of water quality samples that will be shipped to the state-certified or third party- or EPA-accredited analytical laboratory for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the state-certified or third party- or EPA-accredited analytical laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory.

10.4 Analytical Schedule

During Verification Testing for coagulation and filtration treatment equipment, the feedwater (raw water) quality, filtered water quality, (and if applicable, the clarified water quality) shall be characterized by measurement of the following water quality parameters:

- temperature (daily)
- pH (daily)
- total alkalinity (daily)
- hardness (weekly)
- total organic carbon (weekly)
- UV_{254} absorbance (weekly)
- turbidity (daily at bench to check continuous turbidimeters)
- aluminum (weekly if an aluminum salt coagulant is used)
- iron (weekly)
- manganese (weekly if above 0.05 mg/L in feed water)
- algae, number and species (weekly)
- true color (weekly)
- feed water turbidity and particle counts (at least once per 4 hours with grab samples, or continuous monitoring)
- filtered water turbidity and particle counts (continuous)

Table 4. Analytical Methods			
Parameter	Facility	*Standard Methods*[1] number or Other Reference Method	EPA Method[2]
Temperature	On-Site	2550 B	
pH	On-Site	4500-H^+ B	150.1 / 150.2
Total Alkalinity	Lab	2320 B	
Total Harness	Lab	2340 C	
Total Organic Carbon	Lab	5310 C	
UV254 Absorbance	Lab	5910	
Turbidity	On-Site	2130 B / Method 2	180.1
Particle Counts (electronic)	On-Site	Manufacturer	
Aluminum	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Iron	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Manganese	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Algae, number and species	Lab	10200 and 10900	
True Color	On-Site	2120 B (Hach Company modification of SM 2120 measured in spectrophotometer at 455 nm)	
Total Coliform	Lab	9221 / 9222 / 9223	
E. Coli	Lab	9221 / 9222 / 9223 (Colilert)	
Micrococcus l.	Lab	AWWARF Surrogate Report by CSU	
Bacillus spores	Lab	Rice et al. 1996	
MS2 virus	Lab		EPA ICR Method for Coliphage Assay, 1996
Algae	Lab	AWWARF Surrogate Report by CSU	
Cryptosporidium	Lab	NSF and EPA may consider alternative methods if sufficient data on precision, accuracy, and comparative studies are available for alternative methods.	EPA 1622, EPA 1623

Notes:
1) *Standard Methods* Source: 20th Edition of *Standard Methods* for the Examination of Water and Wastewater, 1999, American Water Works Association.
2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Turbidity and particle counts in feed water samples may be measured on a batch or a continuous basis. If batch measurements are made, they shall be made at regular time intervals of four hours or less on each working day during Verification Testing. Filtered water analysis shall be done using continuous flow turbidimeters and flow-through particle counters, equipped with recording capability so data can be collected on a 24-hour-per-day basis during Verification Testing.

The above water quality parameters are listed to provide verification report readers with background data on the quality of the feed water being treated and the quality of the filtered water. These data are to be collected to enhance the usefulness of the Verification Testing data to a wide range of verification report readers.

10.5 Evaluation Criteria

Evaluation of water quality in this task is related to meeting the water quality objectives indicated by the Manufacturer.

Turbidity results shall be analyzed to determine the percentage of turbidity data in the range of 0.10 NTU or lower, the percentage in the range from 0.11 NTU up to 0.20 NTU, the percentage in the range from 0.21 NTU up to 0.34 NTU, the percentage from 0.35 NTU up to 0.54 NTU, and the percentage that were 0.55 NTU or greater. The percentage of filtered water turbidity results that exceed 1.0 NTU shall also be noted. In addition the frequency of occurrence in which the filter was placed into service after backwashing and subsequently produced filtered water turbidity exceeding 0.5 NTU after a four hour ripening period (i.e. the turbidity did not fall to below 0.5 NTU within four hours of starting the filter) shall be noted. The time intervals used for determining turbidity values shall be the same for all data analyzed, and because continuous turbidimeters are to be used to collect turbidity data, the intervals shall be between 5 and 15 minutes.

Particle count data shall be evaluated by calculating the change in total particle count from feed water to filtered water, expressing the change as log reduction. The aggregate of particle counting data obtained during each verification testing period shall be analyzed to determine the median log removal and the 95th percentile log removal during that verification testing period. Uniform time intervals of between 1 hour and 4 hours shall be used to evaluate particle counting data for calculating log reduction of particles in all filter runs. Additional data analysis requirements for particle counting are given in Task 5.

11.0 TASK 3: DOCUMENTATION OF OPERATING CONDITIONS AND TREATMENT EQUIPMENT PERFORMANCE

11.1 Introduction

During each day of Verification Testing, operating conditions shall be documented. This shall include descriptions of pretreatment chemistry for coagulation and of treatment processes used and their operating conditions. In addition, the performance of the water treatment equipment shall be documented, including rate of filter head loss gain, frequency and duration of filter washing, and need for cleaning of pretreatment clarifiers.

11.2 Objectives

The objective of this task is to accurately and fully document the operating conditions that applied during treatment, and the performance of the equipment. This task is intended to result in data that describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

11.3 Work Plan

During each day of Verification Testing, treatment equipment operating parameters for both pretreatment and filtration will be monitored and recorded on a routine basis. This shall include a complete description of pretreatment chemistry; mixing and flocculation intensities, if applicable; operating parameters for clarification ahead of filtration; rate of flow; and filtration rate. Data on filter head loss and backwashing shall be collected. Electrical energy consumed by the treatment equipment shall be measured, or as an alternative, the aggregate horsepower of all motors supplied with the equipment could be used to develop an estimate of the maximum power consumption during operation. Performance shall be evaluated to develop data on chemical dosages needed and on energy needed for operation of the process train being tested. Data shall be developed on the physical and chemical character of wastes or residues produced such as backwash water and sedimentation basin sludge. Data shall also be developed on the rates of waste production, expressed in terms of quantity of waste produced per thousand gallons of water filtered.

A complete description of each process shall be given, with data on volume and detention time of each process basin at rated flow. Data on the filter shall be provided and shall include the depth, effective size, and uniformity coefficient of each layer of filtering material and support material. The type of material used in each layer of filtering material and support material shall be stated. The location of each point for chemical or polymer addition shall be documented. System reliability features including redundancy of components, shall be described. Spatial requirements for the equipment (footprint) shall be stated.

11.4 Schedule

Table 5 presents the schedule for observing and recording coagulation and filtration equipment operating and performance data.

11.5 Evaluation Criteria

Where applicable, the data developed from this task will be compared to statements of performance objectives.

If no relevant statement of performance capability exists, results of operating and performance data will be tabulated for inclusion in the Verification Report.

Table 5. Equipment Operating Data	
Operating Data	Action
Chemicals Used	Record name of chemical, supplier, commercial strength, dilution used for stock solution to be fed (if diluted) for every chemical fed during treatment.
Chemical Feed Volume and Dosage	Check and record each 2 hours. Refill as needed and note volumes and times of refill.
RPM of Rapid Mix and Flocculator	Check once/day and record.
Feedwater Flow and Filter Flow	Check and record each two hours, adjust when >10% above or below goal. Record both before and after adjustment.
Filter Head Loss	Record initial clean bed total head loss at start of filter run and record total head loss each two hours.
Filtered Water Production	Record gallons of water produced per square foot of filter area, for each filter run. [This figure is the product of filtration rate (gpm/sf) and length of filter run in minutes for a filter run performed at constant rate.]
Filter Backwash	Record time and duration of each filter washing. Record water volume used to wash filter.
Clarifier/flocculator or other similar process ahead of filter	If clarifier/flocculator is backwashed separately from backwashing of filter, record the time of every backwash for this process, and volume of water used.
DAF scum removal	Record frequency of scum removal action each day.
DAF recycle flow	Record recycle water flow rate each 8 hours.
DAF saturator pressure	Record DAF saturator vessel pressure each 8 hours.
Electric Power	Record meter reading once per day
Hours operated per day	Record in log book at end of day or at beginning of first shift on the following work day.
All parameters will be checked only during times when the equipment is staffed.	

12.0 TASK 4: MICROBIOLOGICAL CONTAMINANT REMOVAL (OPTIONAL)

12.1 Introduction

Removal of microbiological contaminants is a primary purpose of filtration of surface waters. Consequently, the effectiveness of coagulation and filtration treatment processes for microbial removal will be evaluated in this task. In this task, assessment of treatment efficacy will be made on the basis of removal of one or more microorganisms and on the basis of particle counting.

12.2 Experimental Objectives

The objective of this task is to evaluate removal of microbiological contaminants during Verification Testing by measuring the concentration of particles in feed water and filtered water or the density of microorganisms naturally present in the feed water and filtered water or by seeding the feed water with algae, bacteria, MS2 coliphage, or protozoa, or with a combination of those types of microorganisms, measuring the organism densities in the feed water and filtered water, and calculating the removal.

12.3 Work Plan

Task 4 shall be carried out during the Verification Testing runs being conducted in Task 1. The treatment equipment shall be operated using the chemical pretreatment conditions that provide effective clarification (if used) and filtration.

Microbiological testing may be performed by seeding one or more of the kinds of organisms listed in Table 7 into the feed water or by testing for ambient organisms in the feed water, and by analyzing for the organisms in question in the filtered water.

A minimum of three test runs shall be conducted to provide verifiable microorganism removal data that can be analyzed statistically as described in Task 5 of this Test Plan. Samples shall be collected from the feed water, clarifier (if used) effluent, and the filter effluent to determine microorganism removal through the system.

12.3.1 Bacteria Naturally Present

If sufficient numbers of bacteria are naturally present in the feed water so that 3-log removal can be calculated without seeding bacteria, treatment equipment shall be operated as usual in Verification Testing runs, and sampling shall be done as stipulated in the Analytical Schedule.

12.3.2 Seeded Microorganisms

Seeded organisms shall be used in densities sufficient to permit calculation of at least 3-log removal, and seeding of microorganisms shall begin at start-up of the treatment equipment. The organism feed suspension will be prepared by diluting the organisms to be seeded into dilution water that is distilled or deionized and disinfectant free. The feed reservoir for the organism suspension shall be made of biologically inert material (i.e., not toxic to the organisms in the suspension.) The reservoir will be mixed continuously throughout the experiment and kept packed in ice in a cooler. The seed suspension will be fed into the feedwater using an adjustable rate chemical feed pump. Mixing of this suspension with the feedwater will be accomplished using an in-line static mixer.

For the protozoa challenges, sampling procedures and *Giardia* and *Cryptosporidium* enumeration procedures outlined in EPA Method 1622 or 1623 shall be employed.

For virus (coliphage) challenges water samples of at least 100 mL volume will be collected. Virus (coliphage) samples shall be shipped to a state-certified or third party- or EPA-accredited laboratory for analysis.

For testing in which algae are used as surrogate organisms, the sampling, preservation, and analytical procedures used in the CSU research (see AWWARF report) shall be used.

12.3.3 Organisms Employed for Challenge Tests

Table 6 presents the different microorganisms that may be used for microbial removal studies. These organisms represent a wide variety of types and sizes of microorganisms. Two algae, three bacteria, two protozoan cysts, and one virus are identified for use. Testing may be done with the microorganisms of interest or with surrogates. If surrogates are employed, particle counting and one or more surrogate organisms should be employed as surrogates, i.e., use multiple surrogates.

Table 6. Microorganisms and Surrogates for Coagulation and Filtration Testing

Microorganism	Surrogate (based on research results)	Source
Cryptosporidium parvum oocysts	*Giardia lamblia* cysts	seeded
	Chodatella quadriseta algae*	seeded
	Bacillus bacteria	ambient water or seeded
	E. coli bacteria	seeded
	MS2 coliphage	seeded
Giardia cysts	*Stichococcus subtilis* algae*	seeded
	Bacillus bacteria*	ambient water
	E. coli bacteria	seeded
	*Micrococcus l.** bacteria	seeded
	MS2 coliphage	seeded
Human Enteroviruses	MS2 coliphage	seeded

*recommended as surrogate in draft CSU report to AWWARF

Challenge testing with *Cryptosporidium parvum* or *Giardia lamblia*, or both, can be carried out, as numerous studies, including some cited in the list of references, have shown. The very high cost of testing with *Cryptosporidium* and *Giardia* makes this an unattractive and probably unaffordable option for verification of equipment performance. If studies are carried out with these organisms, it may not be possible in many cases to employ viable protozoan cysts and oocysts for seeding studies, depending upon where the equipment verification is being performed. In such a case, organisms fixed in no more than 5% formalin may be used.

MS2 bacterial virus was identified for use as the model virus for the optional virus challenge studies. MS2 virus is the virus of choice for challenge studies because it is similar in size (0.025 μm), shape (icosahedron) and nucleic acid (RNA) to polio virus and hepatitis. This bacterial virus is the suggested organism to use in the SWTR Guidance Manual when conducting studies of microbial removal (USEPA, 1989). Furthermore, results from research at CSU (Table 6) suggests that MS2 removal results generally understate protozoan removal results, so it is considered a suitable surrogate for *Giardia* and *Cryptosporidium* as well.

Research conducted at Colorado State University developed data indicating that algae could be used as surrogates for protozoan cysts and oocysts. Algae must be cultured and identified by optical microscope. The analytical technique is, however, much less complicated than protozoan analysis. *Chodatella quadriseta*, an oval organism about 3 x 5 μm in size (Cushen et al., 1996) can be used as a surrogate for *Cryptosporidium*. *Stichococcus subtilis*, a rod-shaped organism about 3 x 7 μm in size (Cushen et al., 1996) can be used as a surrogate for *Giardia*. Details regarding procedures for growing and harvesting algae cells for use as surrogates in filtration testing will be found in the AWWA Research Foundation's report on the project "Biological Particle Surrogates for Filtration Performance Evaluation." (in press)

Bacteria can be used as surrogates for protozoan cysts and oocysts. Previous research at CSU (Al-Ani et al., 1986) identified TC bacteria as a potential surrogate for *Giardia* cysts. The recent work at CSU indicates that *Bacillus* bacteria can be used as a surrogate for *Giardia*, as can *Micrococcus l.* *Bacillus* has been evaluated as a surrogate for coagulation and filtration testing by Rice et al. (1996), who stated, "Monitoring for indigenous spores of aerobic sporeforming bacteria represents a viable method for determining treatment plant performance. Comparison of spore levels in source water and filter effluents provides an indication of biological particle removal efficiency." Rice et al. evaluated both naturally occurring *Bacillus* bacteria and cultured *Bacillus subtilis* spores purchased from a commercial laboratory. Analysis of the CSU data developed for AWWARF also indicates that *E. coli* could be a useful surrogate for protozoan cysts and oocysts. This finding could be anticipated from the work of Al-Ani et al., as *E. coli* is a part of the TC group.

12.4 Analytical Schedule

This schedule applies to the test runs (minimum of three) in which microbiological sampling and analysis are undertaken.

Turbidity and particle counts in feed water and filtered water shall be measured in conjunction with microbiological sampling in this task. This is in addition to turbidity and particle count analysis undertaken on a routine basis in Task 2.

Microbiological samples shall be collected from the plant influent (feed water after seeding, if organisms are seeded for challenge studies), clarifier effluent if a clarification step is employed ahead of filtration, and the filter effluent. Samples shall not be collected until the treatment plant has been in operation for a total of 3 theoretical detention times as measured through the pretreatment process up to the filter. For microbiological sampling purposes, the time of operation when 3 pretreatment detention times have elapsed shall be considered time zero. Microbiological samples shall be collected at time zero and at 1, 3, and 6 hours past time zero (or samples shall be collected at a minimum of zero and one-half hour, 1, and 2 hours past time zero). Thereafter microbiological samples shall be collected once every 6 hours until the end of the filter run. In each of the filter runs

conducted to provide verifiable microorganism removal data (a minimum of three runs), one set of microbiological samples shall be collected after the filter has developed approximately 90 percent of terminal head loss, based on experience of prior runs. In addition, if a turbidity breakthrough episode occurs in the filter run, a set of microbiological samples shall be collected during the turbidity breakthrough episode. For purposes of Verification Testing for coagulation and filtration treatment equipment, turbidity breakthrough is defined as a circumstance in which turbidity rises to 0.5 NTU or higher. During each sampling event, four 1-liter samples (for organisms other than protozoa) will be collected. Whenever grab samples are collected for microorganisms, grab samples shall also be collected for turbidity. Particle counting data shall be obtained at the time of sample collection for microorganisms and turbidity and shall be treated (for purposes of statistical analysis described in Task 5) as if those particle counting data were grab sample data. The exact time of sampling will be recorded for each set of grab samples collected so the statistical analysis of grab sample data and particle counting data can be coordinated.

The Testing Organization shall then submit collected water samples to a state-certified or third party- or EPA-accredited laboratory for microbial testing.

12.5 Evaluation Criteria

When microbiological testing is conducted with protozoan cysts or oocysts or with surrogate microorganisms, the microbiological results will be compared to the Manufacturer's statement of performance objectives. Turbidity and particle counting data shall be evaluated as previously described in Task 2.

13.0 TASK 5: DATA MANAGEMENT

13.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software and manual recording of operational parameters for the water treatment equipment on a daily basis.

13.2 Experimental Objectives

One objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Testing Organization provides sufficient and reliable operational data for verification purposes. A second objective is to develop a statistical analysis of the data, as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies."

13.3 Work Plan

13.3.1 Data Handling

The following protocol has been developed for data handling and data verification by the Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters

should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels will be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data will be manipulated into a convenient framework to allow analysis of water treatment equipment operation. Backup of the computer databases to diskette should be performed on a monthly basis at a minimum.

In the case when a SCADA system is not available, field testing operators will record data and calculations by hand in laboratory notebooks. (Daily measurements will be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook will provide carbon copies of each page. The original notebooks will be stored on-site; the carbon copy sheets will be forwarded to the project engineer of the Testing Organization at least once per week. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include a description of the water treatment equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project will be set up in the form of custom-designed spreadsheets. The spreadsheets will be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheet. Data entry will be conducted on-site by the designated field testing operators. All recorded calculations will also be checked at this time. Following data entry, the spreadsheet will be printed out and the print-out will be checked against the handwritten data sheet. Any corrections will be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet will be printed out. Each step of the verification process will be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each filtration test run) will be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA-accredited analytical laboratories, the data will be tracked by use of the same system of run numbers. Data from the outside laboratories will be received and reviewed by the field testing operator. These data will be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

13.3.2 Statistical Analysis

Water quality data developed from grab samples collected during filter runs according to the Analytical Schedule in Task 4 of this Test Plan shall be analyzed for statistical uncertainty. The Testing Organization shall calculate 95% confidence intervals for grab sample data obtained during Verification Testing as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies." Statistical analysis could be carried out for a large variety of testing conditions. For example, situations such as all test run data for optimized coagulation with a specified coagulant chemical and at a specified rate of flow for

the treatment plant equipment, would provide a data base for which statistical analysis might be appropriate. Two conditions that are specifically required to be analyzed statistically are:

- for runs involving microbiological sampling, all grab sample test data after the initial improvement period (filter ripening) and before turbidity breakthrough, analyzed separately for each filter run, to show the extent of performance variability during optimum operating conditions of each run, and;

- for runs involving microbiological sampling, all grab sample test data collected from the start of the run through the completion of the run, analyzed separately for each filter run, to show the extent of performance variability during each complete filter run.

The statistics developed will be helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals. Information on the differences in water quality variations for entire filter runs versus the quality produced during the optimized portions of the runs would be useful in evaluating appropriate procedures for starting and terminating filter runs.

14.0 TASK 6: QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

14.1 Introduction

Quality assurance and quality control of the operation of the water treatment equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 Work Plan

Equipment flow rates and associated signals should be documented and recorded on a routine basis. A routine daily walk-through during testing will be established to verify that each piece of equipment or instrumentation is operating properly. Particular care will be taken to confirm that any chemicals are being fed at the defined flow rate into a flow stream that is operating at the expected flow rate, such that the chemical concentrations are correct. In-line monitoring equipment such as flow meters, etc. will be checked to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

14.4 Daily QA/QC Verifications:

- Chemical feed pump flow rates (verified volumetrically over a specific time period)
- In-line turbidimeters flow rates (verified volumetrically over a specific time period)
- In-line turbidimeter readings checked against a properly calibrated bench model
- Batch and in-line particle counters flow rates (verified volumetrically over a specific time period).

14.5 QA/QC Verifications Performed Every Two Weeks:

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

14.6 QA/QC Verifications for Each Testing Period:

- In-line turbidimeters (clean out reservoirs and recalibrate)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)
- Particle counters (perform microsphere calibration verification)

14.7 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of raw water and filtered water quality are described in the section below. In-line equipment is recommended for its ease of operation and because it limits the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. In-line equipment is recommended for measurement of turbidity and for particle counting for feed water and is required for measurement of turbidity and for particle counting for filtered water.

14.7.1 pH

Analysis for pH shall be performed according to *Standard Methods* 4500-H^+ or EPA Methods 150.1/150.2. A three-point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

14.7.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Method* 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1°C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1°C to +51°C, subdivided in 0.1° increments, would be appropriate for this work.)

14.7.3 Color

True color shall be measured with a spectrophotometer at 455 nm, using an adaptation of the *Standard Methods* 2120 procedure. Samples shall be collected in clean plastic or glass bottles and analyzed as soon after collection as possible. If samples can not be analyzed immediately they shall be stored at $4^{o}C$ for up to 24 hours, and then warmed to room temperature before analysis. The filtration system described in *Standard Methods* 2120 C shall be used, and results should be expressed in terms of PtCo color units.

14.7.4 Turbidity Analysis

Turbidity analyses shall be performed according to *Standard Method* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters shall be used for measurement of turbidity in the filtrate waters, and either an in-line or bench-top turbidimeter may be sued for measurement of the feedwater.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any subsequent modifications or enhancements made to monitoring instruments.

14.7.4.1 Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of equipment operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples dial cause the vial to fog preventing accurate readings, allow the vial to warm up by submersing partially into a warm water bath for approximately 30 seconds.

14.7.4.2 In-line Turbidimeters. In-line turbidimeters are required for filtered water monitoring during verification testing and must be calibrated as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is

not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

14.7.5 Particle Counting

In-line particle counters shall be employed for measurement of particle concentrations in filtrate waters. However, either a bench-top or an in-line particle counter may be used to measure particle concentrations in the feedwater, concentrate (where applicable) and pretreated waters (where applicable). Laser light scattering or light blocking instruments are recommended for particle counting during verification testing. However, other types of counters such as Coulter counters or Elzone counters may be considered for use if they can be configured to provide continuous, in-line monitoring for the filtrate product water stream. The following discussion of operation and maintenance applies primarily for use of laser light blocking instruments.

The following particle size ranges (as recommended by the AWWARF Task Force) shall be monitored by both in-line and bench-top analytical instruments during the verification testing:

- 2-3 μm
- 3-5 μm
- 5-7 μm
- 7-10 μm
- 10-15 μm
- > 15 μm

The Field Testing Organization shall be required to document any problems experienced with the monitoring particle counting instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

Use of particle counting to characterize feedwater and filtered water quality is required as one surrogate method for evaluation of microbiological contaminant removal.

14.7.5.1 Bench-top Particle Counters. All particle counting shall be performed on site. The particle sensor selected must be capable of measuring particles as small as 2 μm. There should be less than a ten percent coincidence error for any one measurement.

Calibration. Calibration of the particle counter is generally performed by the instrument manufacturer. The calibration data will be provided by the manufacturer for entry into the software calibration program. Once the data has been entered it should be verified using calibrated commercially-available particle standards or methods. This calibration should be verified at the beginning of each Verification Testing period.

Maintenance. The need for routine cleaning of the sensor cell is typically indicated by: 1) illumination of the sensor's "cell" or "laser" lamps, 2) an increase in sampling time from measurement to measurement, or 3) an increase in particle counts from measurement to measurement. During the ETV testing, the sensor's "cell" and "laser" lamps and the sampling time will be checked periodically. The number of particles in the "particle-free water" will also be monitored daily.

Particle-Free Water System. "Particle-free water" (PFW) will be used for final glassware rinsing, dilution water, and blank water. This water will consist of de-ionized (DI) water that has passed through a 0.22-μm cartridge filtration system. This water is expected to contain fewer than 10 total particles per mL, as quantified by the on-site particle counter.

Glassware Preparation. All glassware used for particle counting samples shall consist of beakers designed specifically for the instrument being used. Glassware will be cleaned after every use by a triple PFW rinse. Sample beakers will then be stored inverted. Dedicated beakers will be used at all times for unfiltered water (raw, pre-oxidized, flocculated), diluted unfiltered water, filtered water, and PFW. When several samples are collected from various equipment sampling points during one day, the appropriate beakers will be hand-washed as described above, and then rinsed three times with sample prior to collection. Other materials in contact with the samples, including volumetric pipettes, volumetric flasks, and other glassware used for dilution, will also be triple-rinsed with both PFW and sample between each measurement.

Sample Collection. Beakers should be rinsed with the sample at least three times prior to sample collection for particle counting. Sample taps should be opened slowly prior to sampling. Sudden changes in the velocity of flow through the sampling taps should be avoided immediately prior to sample collection to avoid scouring of particles from interior surfaces. A slow, steady flow rate from the sample tap will be established and maintained for at least one minute prior to sample collection. The sample will be collected by allowing the sample water to flow down the side of the flask or beaker; thereby minimizing entrainment of air bubbles.

Dilution. The number of particles in the raw and pretreated waters (where applicable) is likely to exceed the coincidence limit of the sensor. If so, these samples will be diluted prior to analysis. In all cases, PFW will be used as dilution water. When necessary, dilutions will be performed as follows:

- Dilution water will be dispensed directly into a 500-mL volumetric flask;
- A volumetric pipette (i.e. 10-mL for a 50:1 dilution) will be used to collect an aliquot of the sample to be diluted (stock);
- The appropriate volume of the stock will be slowly added to the volumetric flask containing the dilution water;
- The volumetric flask will be slowly filled to the full-volume etch with dilution water;
- The volumetric flask will be inverted gently and then its contents will be poured slowly into the appropriate 500-mL flask for analysis.

During each of the above steps, care will be taken to avoid entrainment of air bubbles; thus, samples and dilution water will flow slowly down the side of containers to which they are added. Excessive flow rates through pipette tips, which can cause particle break-up, will be

avoided by use of wide-mouth pipettes. Sample water will be drawn into and out of pipettes slowly to further minimize particle break-up.

Actual particle counts in a size range for diluted samples will be calculated based on the following formula:

$$Sample\,Particle\,Concentration = \frac{\{MP - (1 - X) \times PF\}}{X}$$

where MP is the measured particle concentration in the diluted sample, PF is the measured particle concentration in the particle-free water, and X represents the dilution factor. For a 25:1 dilution, the dilution factor would be 1/25, or 0.04.The expression for the dilution factor is provided by the following equation:

$$Dilution\,Factor = X = \frac{Volume\,Sample}{Addition\,of\,Volume\,Sample + Volume\,Dilution\,Water}$$

Particle Counting Sample Analysis. To collect samples for particle counting, at least 200 mL of each water sample to be counted (diluted or not) should be collected in the appropriate beaker. The beaker will be placed into the pressure cell and counting will take place in the "auto" mode of the instrument. Four counts will be made of each sample. The first count will serve to rinse the instrument with the sample; data from this count are discarded. Data from the subsequent three counts will be averaged, and the average value will be reported as the count for that sample.

14.7.5.2 In-line Particle Counters. Any in-line particle sensors selected for use must have capabilities for measurement of particles as small as 2 μm and have a coincidence error of less than ten percent. The particle counter manufacturer shall provide data and methods that the in-line particle sensors meet these criteria or an independent third party shall verify the in-line particle sensor meets the above criteria. The particle counter manufacturer shall provide the methods for demonstration of coincidence error.

The sensors of the in-line units must also be provided with a recent (two months before the start of testing) manufacturer calibration. The calibration shall be verified by measurement of the individual and cocktail suspensions of the monospheres as described for the batch counter; however, in this case the samples must be fed in-line to the counters.

No dilution of the filtered water samples will be conducted. The data acquired from the counters will be electronically transferred to the data acquisition system. If it is known that a particular sensor will not be used for a period of several days or more, refer to the manufacturer recommendations for an appropriate storage protocol.

14.8 Chemical and Biological Samples Shipped Off-Site for Analyses

14.8.1 Organic Parameters: Total Organic Carbon and UV_{254} Absorbance

Samples for analysis of TOC and UV_{254} absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held, and shipped in accordance with Standard Method 5010B. Storage time before analysis shall be minimized, according to *Standard Methods*.

14.8.2 Microbial Parameters: Total Coliform, Viruses, Bacteria, Protozoa, and Algae

Samples for analysis of Total Coliforms (TC) shall be collected in bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped with an internal cooler temperature of approximately 4°C to the analytical laboratory. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited analytical laboratory within the time specified for the relevant analytical method. The laboratory shall keep the samples at approximately 4°C until initiation of analysis. TC densities will be reported as most probable number per 100 mL (MPN/100 mL) or as TC densities per 100 mL.

Other microbiological samples shall be refrigerated at approximately 4°C immediately upon collection. Such samples shall be shipped with an internal cooler temperature of approximately 4°C to the analytical laboratory. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited analytical laboratory within the time specified for the relevant analytical method.

Algae samples shall be preserved with Lugol's solution after collection, stored and shipped in a cooler at a temperature of approximately 4°C, and held at that temperature range until counted.

14.8.3 Inorganic Samples

Inorganic chemical samples, including alkalinity, hardness, aluminum, iron and manganese, shall be collected and preserved in accordance with *Standard Methods* 3010B, paying particular attention to the sources of contamination as outlined in *Standard Methods* 3010C. The samples shall be refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C. Samples shall be processed for analysis by a state-certified or third-party- or EPA-accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

15.0 OPERATION AND MAINTENANCE

The Field Testing Organization shall obtain the Manufacturer-supplied O&M manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for O&M Manuals for equipment employing coagulation and filtration.

15.1 Maintenance

The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- valves
- chemical feeders
- mixers
- motors
- instruments, such as streaming current monitors or turbidimeters
- water meters, if provided

The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- tanks and basins
- in-line static mixers
- filter vessels

15.2 Operation

The manufacturer should provide readily understood recommendations for procedures related to proper operation of the equipment. Among the operating aspects that should be discussed are:

Chemical feeders:

- calibration check
- settings and adjustments -- how they should be made
- dilution of chemicals and polymers -- proper procedures

Mixers and flocculators:

- purpose
- changing intensity (RPM), if available

Filtration:

- control of filtration rate
- observation and measurement of head loss during filter run

Filter washing:

- end of filter run
- use of auxiliary water scour (surface wash) or air scour
- start of backwash
- appropriate backwash rates
- conclusion of filter washing
- return of filter to service

Monitoring and observing operation:

- observation of floc
- pretreated water turbidity, if appropriate
- filtered water turbidity
- filter head loss
- what to do if turbidity breakthrough occurs

Coagulant dose selection:
Strongly recommend that Manufacturer include a copy of AWWA Manual M37, "Operational Control of Coagulation and Filtration Processes" with each coagulation and filtration system, as an AWWA committee of experts has prepared an excellent manual that would be very helpful to plant operators.

The manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- no raw water (feed water) flow to plant
- poor raw water quality (raw water quality falls outside the performance range of the equipment)
- can't control rate of flow of water through equipment
- no chemical feed
- mixer or flocculator will not operate (won't rotate)
- filter can't be backwashed or backwash rate of flow can't change
- no reading on turbidimeter or streaming current monitor
- automatic operation (if provided) not functioning
- filtered water turbidity too high
- filter head loss builds up excessively rapidly
- no head loss readings
- valve stuck or won't operate
- no electric power

It is also recommended that the Manufacturer add a toll free number to the O&M manual for technical assistance on operation and maintenance of the equipment.

The following are recommendations regarding operability aspects of equipment employing coagulation and filtration. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of equipment testing when the testing is done under the ETV Program.

During Verification Testing and during compilation of historical equipment operating data, attention shall be given to equipment operability aspects. Among the factors that should be considered are:

- fluctuation of chemical feed rate from desired value -- the time interval at which re-setting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?)
- presence of devices to aid the operator with chemical dosage selection:
- streaming current monitor provided?
- influent and filtered water continuous turbidimeters provided?
- pilot filter provided?
- can backwash be done automatically?
- if automatic backwash provided, could it be initiated by:
- reaching a set value for head loss?
- reaching a set value for filtered water turbidity?
- does remote notification to operator occur when backwash happens?
- can operator observe filter backwash?
- how can plant operator check on condition and depth of filter media?
- can flocculation energy be varied?
- does plant have multiple feed points for chemicals:
- for pH adjustment?
- for coagulant chemical feed?
- for polymer feed?
- is head loss measurement provided?
- is rate of flow of raw water measured?
- is chemical feed paced with raw water flow?
- is backwash rate of flow measured and variable?
- is backwash duration (time) variable?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Task 3: Operating Conditions and Treatment Equipment Performance, in the Coagulation and Filtration Test Plan.

16.0 REFERENCES

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APPENDIX 3A

OPTIONAL EXTRA TASK FOR EVALUATING REDUCTION OF TRIHALOMETHANE FORMATION POTENTIAL BY COAGULATION AND FILTRATION

Introduction

Coagulation and filtration processes have been shown to be capable of reducing the organic precursor materials that form trihalomethanes (THMs) and haloacetic acids (HAAs) in a wide variety of waters. Each feed water may be somewhat different from other feed waters, but evaluation of the capability for removal of DBP precursor at sites where coagulation and filtration testing is done for control of particulate and microbiological contaminants could be advantageous in terms of obtaining data related to other water quality concerns at a relatively nominal cost.

Objective

This optional task, if carried out, is done to assess removal of organic materials that can form DBPs upon chlorination. Removal of DBP precursors is variable, depending on the nature of the organics in the source water or feed water. Data on DBP precursor removal shall be obtained by evaluating THM precursor removal and by evaluating HAA precursor removal.

Work Plan

During the verification testing runs in coagulation and filtration testing, water samples shall be collected and THM formation potential and HAA formation potential testing of both feed water and filtered water shall be performed. NOTE: This task shall not be undertaken if a disinfectant other than ozone is used prior to filtration. Samples collected for evaluation of DBP precursor removal shall be set up according to Method 5710B, Trihalomethane Formation Potential, in *Standard Methods*. The incubation conditions and other requirements of Method 5701B shall be followed without deviation. Unless the NSF-qualified testing organization has laboratory capabilities for doing this work, these samples should be collected and shipped in suitably prepared glass bottles to an analytical laboratory where sample set-up and incubation and THM analysis HAA analysis can be performed.

Water treatment practice can influence removal of DBP precursor. Treatment plant operating data that shall be collected in conjunction with sampling for DBP formation potential determination include:

- pH of coagulated water
- alkalinity of feed water and filtered water
- type of coagulant chemical used, and dosage
- temperature during treatment
- TOC of feed water and filtered water

Analytical Schedule

During each verification testing period, on four different days on which verification testing runs are being carried out, one sample of feed water and one sample of filtered water shall be obtained and set up for THM and HAA formation potential, or shall be shipped to a state-certified or third party- or

EPA-accredited laboratory for set-up. At the end of the specified incubation time, the samples shall be analyzed for THMs and HAAs.

Evaluation Criteria

The concentrations of DBPs that form in water distribution systems (where regulatory compliance samples must be obtained by water systems) are influenced by many factors beyond the control of the treatment plant operator and the coagulation and filtration process. Therefore data analysis shall consist only of calculation of the mean reduction of THM formation potential and HAA formation potential by coagulation and filtration for each period of testing. No minimum percentage of reduction is specified for comparison purposes. The report shall simply state the extent to which THM formation potential could be reduced by coagulation and filtration, along with the coagulant chemical, dosage used, and pH of coagulation when the test results were obtained. The report shall also state the extent to which HAA formation potential could be reduced under the same conditions of coagulant chemical type, dosage used, and coagulation pH for which THM formation potential reduction was reported.

APPENDIX 3B

USE OF SURROGATES FOR ESTIMATING MICROORGANISM REMOVAL IN COAGULATION AND FILTRATION TESTING

Microorganism Removal -- Direct Evaluation versus Surrogates

Evaluation of coagulation and filtration treatment processes for microbiological contaminant removal can be done directly by measurement of microorganisms of concern in the feed water and in the filtered water. This approach provides a direct assessment of the removal capability of a water treatment process train, but its use is limited to natural waters (feed waters) having sufficiently high densities of microorganisms that comparison of feed water and filtered water densities can be used to calculate percentage reductions or log removals. It is desirable to have sufficient numbers of organisms in feed water such that if no organisms are detected in filtered water, 3-log or 4-log removal (99.9% or 99.99% removal) could be calculated. Many natural waters do not have the high densities of protozoan organisms necessary to show the true removal capability of treatment processes. It is of little value to be able to state that based on the numbers of organisms found in feed water and with none found in filtered water, the removal exceeded 90% when in fact if sufficient numbers of organisms had been present removal might have exceeded 99% or 99.9%.

One approach to evaluating removal of viruses or protozoa would be to measure feed water and filtered water organism densities at existing treatment plants using equipment, providing the feed water had sufficiently high numbers of viruses or protozoa. This approach would also require that no disinfectant was applied to the water before filtration, so that the entire reduction of microorganisms could be attributed to physical removal. An existing treatment plant that provided drinking water to a community would not be an appropriate facility for spiking or seeding viruses or protozoa, because of public health concerns.

A different approach might be taken at a water treatment facility that had been installed solely for verification of performance capability. At an installation where no drinking water is produced, seeding viruses or protozoa into feed water might be feasible, depending on the feed water flow, the desired density of organisms in the feed water, and the cost of this undertaking.

Another technique for assessing the potential for removal of microorganisms is through the use of surrogates in place of viruses and protozoa. Analyzing water samples for human enteric viruses, *Cryptosporidium* oocysts, and *Giardia* cysts is complex and expensive. In the case of *Cryptosporidium*, the analytical method is acknowledged to have many uncertainties, including poor recovery of oocysts from the water that was sampled. As a result of the uncertainties associated with analytical data for human enteroviruses and protozoa, use of less-expensive surrogate measurements may reveal as much as or more than measuring the microorganisms of actual concern.

A number of surrogate indicators of filtration performance for coagulation and filtration treatment trains have been used by researchers. The simplest is turbidity, which does not involve analysis for any microorganisms. Somewhat more complicated, but still avoiding microbiological analysis, is use of particle counting, either by using electronic particle counters or by counting a particular type of particle that was seeded into the feed water. Use of biological surrogates involves analysis for natural organisms or seeded organisms that are simpler and easier to detect than the protozoa and viruses. Each of the surrogate techniques mentioned above is described in the paragraphs below.

Use of multiple surrogates is recommended to compensate for the problem that no surrogate perfectly reproduces the behavior of the protozoan organisms. Even though particle counting is conservative with regard to removal of microorganisms, use of particle counting is a recommended technique because particle counters can be operated continuously to permit detailed observation of filtered water quality and temporary, short-term changes in that quality. Use of one or more microorganisms as a surrogate is also recommended to ascertain a better estimate of actual biological particle removal than can be determined by particle counting.

Turbidity as a Surrogate

Relationships between turbidity removal and microorganism removal have been noted by some investigators but not others. Hibler and Hancock (1990) reported on a data base of 20 conventional treatment plants in which turbidity reductions of about 85% or greater resulted in *Giardia* cyst reductions exceeding 90% in 18 of the 20 plants, but they did not provide information on the filtered water turbidity. In an extensive filtration research project, turbidity removal did not correlate well with removal of *Giardia* or *Cryptosporidium*, because turbidity was removed to a much lesser extent than those microorganisms (Patania et al. (1995). Al-Ani et al. (1986) combined the concepts of turbidity removal and filtered water turbidity, reporting, "...if turbidity removal exceeded 70 percent and if filtered water turbidity was lower than 0.10 NTU, the probability was 0.85 (37/44) that the removal of *Giardia* cysts would equal or exceed 99 percent. The work of Al-Ani et al. was done with feed water having turbidity of 1 NTU or less.

The association of low filtered water turbidity with high removal of various microorganisms and particles has been made for over three decades by various researchers who have studied coagulation and filtration. Turbidity measurement is based upon scattered light, and it is not a direct measure of particles in water, nor can it give any information on particle size; nevertheless, general relationships for filtered water turbidity and filter performance have been developed over the past three or four decades. Robeck et al. (1962) studied removal of seeded poliovirus and found the best removals (greater than 99.7% for conventional treatment) were associated with turbidities around 0.1 turbidity unit. DeWalle et al. (1984) at the University of Washington found that attaining low filtered water turbidity (about 0.1 NTU) was related to removal of 97% to 99.9% of *Giardia* cysts. Logsdon and Symons (1977) reported that removal of amphibole asbestos fibers, which were larger than viruses but smaller than bacteria, was better when filtered water turbidity was less than 0.2 NTU than when the turbidity was above that value. Patania et al. (1995) attained a median removal of 4.2 log (slightly over 99.99%) for both *Giardia* and *Cryptosporidium* in 105 observations of raw and filtered water samples. Filtered water samples having turbidity between 0.1 and 0.3 NTU, as compared to those with turbidity less than 0.1, were associated with lower removals of organisms, by as much as 1.0 log. Although concentrations of microorganisms in coagulated and filtered water can not be predicted based upon filtered water turbidity, attaining filtered water turbidity of 0.1 NTU or lower has been associated with very effective removal of viruses and protozoan cysts. The same concept held for very small inorganic particles (asbestos fibers) counted by an electron microscope. Attaining very low filtered water turbidity thus is an effective indicator of attaining very good removal of microbes or small particles.

Particle Counting as a Surrogate

Use of particle counting as a surrogate for removal of microorganisms was proposed in EPA's Surface Water Treatment Rule Guidance Manual. Electronic particle counters are much more sensitive to changes in water quality than turbidimeters, and they have the additional advantage of

being able to provide data on sizes of particles in water, which turbidimeters can not do. Particle counters also are able to detect water quality changes in low turbidity waters for which turbidimeters have approached or reached the detection limit for low turbidity. In the turbidity range of 0.02 to 0.10 NTU the magnitude of turbidity variation is much less than the magnitude of particle counts that could be detected.

Users need to be aware of the limitations of particle counting, however. A coagulated and filtered water having between 1 and 10 particles/mL (1000 to 10,000 particles/L) would be considered to have a low particle count. In contrast, the EPA has suggested that one option for controlling *Cryptosporidium* might be to require up to 6-log reduction for raw waters containing more than 100 oocysts/100 L (1 oocyst/L). Based on the performance capability of coagulation and filtration, the use of particle counting to indicate directly that *Giardia* and *Cryptosporidium* are not present in finished waters at concentrations that could cause problems appears to be impossible at present.

A second difficulty with use of particle counting as a surrogate is that all particle counters have some lower size limit for particles, and below that limit particles in water are not counted. Particles in feed water that are too small to be counted before coagulation can be agglomerated together after coagulation and then may form particles large enough to be counted. Flocculation can increase the number of large particles by combining many smaller particles. Finally filtration removes particles, but in a granular media filter attached floc and particles can be sloughed off of the media and can flow out of the filter bed during the filtration process. Because of all of these factors it is highly unlikely that the specific particles in the feed water in a specified size range, such as 3 to 6 μm, are also the 3 to 6 μm particles seen in the filtered water. By coagulation and flocculation, many of the 3 to 6 μm particles counted in the feed water would subsequently be flocculated into larger particles, some of which would be removed in filtration and a few of which might pass through the filter. The myriad changes occurring between feed water and filtered water make it difficult to determine the fate of any given particle in the feed water. The possibility for incorporating smaller sized particles into larger ones introduces uncertainty into calculations of log reduction of particles, particularly in the smaller size ranges. Smaller particles that apparently were removed as indicated by reductions in their concentration in fact may have been incorporated into larger particles that passed through the filter and were counted.

Patania et al. (1995) conducted a very large study of coagulation and filtration for *Giardia* and *Cryptosporidium* removal, and included particle counting in filtration testing. They reported, "Removal of particles in size ranges of 1-2, 2-5, 5-15, and 1-25 μm did not correlate well with removal of either *Cryptosporidium* or *Giardia*. Further, a one-to-one relationship between particle removal and *Cryptosporidium* or *Giardia* removal was not observed, with particle removal consistently lower than organism removal. Use of particle removal as a surrogate for cyst (and oocyst) removal, as is presently recommended in the SWTR Guidance Manual (USEPA 1989), can therefore considerably underestimate cyst and oocyst removal under some conditions, such as the relatively high organism concentrations and relatively low turbidity and particle concentrations occurring in this study." In an attempt to determine the upper limits for filtration performance, very high numbers of cysts and oocysts were seeded into the natural waters used in the Patania et al. pilot study conducted with four different source waters in California, Oregon, and Washington.

Particle counting was also undertaken in a study at Colorado State University sponsored by the AWWA Research Foundation (Hendricks et al., 1996). An analysis of the CSU data was done as a part of the NSF project for Verification Testing. This analysis is presented later in the section on

microbiological surrogates, where comparisons are made between particle removal and microbe removal.

The results of testing by Patania et al. and by Hendricks et al. suggest that straightforward comparisons of *Giardia* or *Cryptosporidium* removal and particle removal can not be made because the reduction of the protozoan organisms often is considerably greater than the reduction of particles.

In spite of the drawbacks, particle counting offers much more information about filtration performance than turbidity measurement, and so it has become a favored means of filter evaluation among many in the field.

Microbiological Surrogates

Numerous researchers have used or recommended using microorganisms as surrogates for other microorganisms in water treatment. Examples include use of *G. muris* as a surrogate for *G. lamblia* in water filtration studies, use of coliphage MS2 as a surrogate for human enteroviruses, and use of TC bacteria as a surrogate for *Giardia* cysts.

Successful use of microorganisms as surrogates requires knowledge of the characteristics of both the target organism and the surrogate. Resistance to disinfectants varies from organism to organism, so use of microbiological surrogates in filtration studies is most appropriate when no disinfectant chemical will be employed until after the filtration process is completed. This eliminates disinfectant resistance as a variable in testing.

Using microorganisms as surrogates has the advantage of working with particles that have negative surface electrical charge (i.e., have negative zeta potential) and have a density close to that of water. According to currently-held theories of how microscopic particles are removed by coagulation and deep bed filtration, both surface charge and density are factors that are related to particle removal. *Giardia* cysts have a density of about 1.05 g/cm^3 (Hibler and Hancock, 1990), and the density of *Cryptosporidium* is similar, because the same gradient centrifugation technique can be used for analysis of both cysts and oocysts. The specific gravity of bacteria is approximately 1 (Gainey and Lord, 1952), and they are 80% water by weight. From the perspective of specific gravity, bacteria and protozoan cysts or oocysts are similar. The zeta potential, or apparent electrical charge close to the surface of particles in water, is negative at neutral pH values for bacteria, protozoan cysts and oocysts, and by inference, for viruses (Cushen, Kugrens, and Hendricks, 1996; Fox and Lytle, 1996). The zeta potential for clay particles and for the great majority of particles found in water is also negative; therefore, using cationic polymers or metal coagulants based on iron or aluminum is the correct approach for lowering or neutralizing the zeta potential of all of the above types of small particles so that they can be agglomerated into larger floc particles or so the small particles will adhere to granular filter media in the filtration process.

Appropriate particle sizes can be selected by using viral surrogates or surrogates in the size range of bacteria or protozoan cysts. Filtration theory and experimental results suggest that 1 μm particles should be more difficult to remove than either larger particles or smaller particles. On this basis, bacteria removal should be as difficult as cyst removal, or more difficult, and bacteria should be a good surrogate for protozoan cysts in coagulation and filtration processes. Studies by Al-Ani et al. (1986) showed that percent removal of total coliform bacteria is a good indicator of percent removal of *Giardia* cysts. In 7 of 52 pairs of samples *Giardia* removal exceeded total coliform removal, ranging from 87 to 93% when total coliform removal was 95% or greater; in 8 of 52 pairs, *Giardia*

removal was 96% or greater but total coliform was 80% or lower; and in 36 of 52 samples both *Giardia* and total coliform removal were 95% or greater. Thus in only about 14% of the sample pairs was the total coliform removal greater than *Giardia* cyst removal. These results suggest that total coliform bacteria may be a useful surrogate for *Giardia* cysts.

The AWWA Research Foundation funded an evaluation of potential surrogate organisms at Colorado State University (Hendricks et al., 1996). Coagulation and filtration pilot plant tests were undertaken with *Giardia* and *Cryptosporidium* plus a number of algae, bacteria, and coliphages as possible surrogates.

The CSU draft report to AWWARF indicated that log removals of the algae *Chodatella quadriseta* could be used to estimate log removals of *Cryptosporidium* with an adjustment factor of 1.06 applied to the algae log removal. The draft report also noted that log removals of the algae *Stichococcus subtilis* could be used directly to estimate log removals of *Giardia*. Both algae species were reported to be easy to culture and to have a distinct appearance under the microscope when water samples were examined to enumerate the algae in feed water or filtered water.

Bacteria could be used as a surrogate for *Giardia* removal. By applying a factor of 1.19 to the log removal of *Bacillus stearotheromophillus*, the log removal for *Giardia* could be estimated. *Micrococcus l.* could be used directly, without a multiplicative factor, to evaluate *Giardia* removal. The draft report also noted that use of bacteria as surrogates may be more practical than using algae since utilities have to monitor for bacteria, but the algae would have to be cultured.

For coagulation and filtration test runs performed at CSU, in which both *Giardia* and *Cryptosporidium* were seeded, and some or all of three potential surrogates (*Bacillus st., E. coli*, coliphage MS2) were included in testing, data are given in Table B-1. These are actual data or calculated results from the individual test runs, which are identified by date. An analysis of log reduction in total particle count is included as well. All of the comments and opinions expressed in this document that are based on Table B-1 are the result of this work and are not to be considered as conclusions of CSU.

Several preliminary conclusions can be drawn from Table B-1.

- Turbidity of the feed water was low, varying from 1 to 3 NTU.

- Except for the run on October 30, the range of log removals for particle count data was narrow, from 1.79 to 2.85 logs.

- Log removals for *Cryptosporidium* were higher than log removals of *Giardia* in 15 of 18 runs when both were seeded. During optimum treatment *Cryptosporidium* removals ranged from 2.46 log to 4.95 log whereas *Giardia* removals ranged from 2.85 log to 4.55 log.

- During non-optimum treatment with inadequate alum doses (runs of Jan 15 and Feb 5) removals of *Giardia* cysts, *Bacillus*, *E. coli*, and MS2 were lower than during the runs with adequate alum doses. (Unfortunately no particle counting data are available for these runs.) In these runs the 2.6-log removals observed for *Cryptosporidium* were similar to the 2.5-log removals observed during two runs with optimum alum doses. Only in those four runs, however, was *Cryptosporidium* log removal less than 3.0.

- Log removals of *Bacillus* and *E. coli* were similar to log removals for coliphage MS2, even though MS2 is about 1/50 the size of the bacteria.

Concerning use of microorganisms as surrogates for protozoans, with respect to log removals:

- Removal of *Bacillus* was less than removal of *Cryptosporidium* in 5 of 8 tests. Removal of *Bacillus* exceeded removal of *Cryptosporidium* in 3 of 8 tests, by 0.2, 0.2, and 0.3 log.

- Removal of *Bacillus* was less than removal of *Giardia* in 7 of 8 tests. Removal of *Bacillus* exceeded removal of *Giardia* in 1 test by 0.4 log.

- Removal of *E. coli* was less than removal of *Cryptosporidium* in 7 of 8 tests. Removal of *E. coli* exceeded removal of *Cryptosporidium* in 1 test by 0.1 log.

- Removal of *E. coli* was less than removal of *Giardia* in 6 of 8 tests. Removal of *E. coli* exceeded removal of *Giardia* in 2 tests by 0.1 and 0.2 log.

- Removal of MS2 coliphage was less than removal of *Cryptosporidium* in 8 of 10 tests. Removal of MS2 exceeded removal of *Cryptosporidium* in 2 tests by 0.4 and 0.7 log.

- Removal of MS2 coliphage was less than removal of *Giardia* in 9 of 10 tests. Removal of MS2 exceeded removal of *Giardia* in 1 test by 0.4 log.

Concerning the removal of particles as a surrogate for removal of microorganisms:

- Particle removal was less than *Cryptosporidium* removal in 15 of 16 tests.

    - Particle removal was less than *Giardia* removal in 16 of 16 tests.

- Particle removal was less than *Bacillus* removal in 7 of 8 tests and exceeded *Bacillus* removal in 1 test by 0.6 log.

- Particle removal was less than *E. coli* removal in 5 of 7 tests and exceeded *E. coli* removal in 2 tests by 0.2 log and 0.6 log.

- Particle removal was less than MS2 removal in 10 of 10 tests, with a maximum difference of 1.0 log.

Particle removal tends to underestimate the removal of viruses, bacteria, and protozoa when used to evaluate results of coagulation and filtration. The surrogate evaluation data developed by Colorado State University indicate that using biological surrogates for protozoan removal may provide closer estimates of protozoan removal than particle counting. This may be the result of the changes that particle size distributions undergo as a result of coagulation and flocculation. Although particle counting can be used to evaluate coagulation and filtration process train performance without parallel use of biological surrogates, use of biological surrogates together with particle counting is recommended as a means of diversifying the surrogates for evaluation of treatment. On the basis of the CSU data, use of coliphage MS2 as a surrogate for enteroviruses and as a surrogate for protozoan removal is appropriate. This organism could be used in seeding studies. In seeding studies, use of *E. coli* in settled domestic sewage could be considered, but this should not be done at a drinking water

treatment plant. In circumstances where a treatment system is being used to treat drinking water for a small water system, if chlorination is not practiced until after filtration, and if the feed water has sufficient numbers of *Bacillus* bacteria, use of *Bacillus* as a surrogate to supplement particle counting is recommended.

Table B-1. AWWARF Surrogate Removal Pilot Plant Data
Coagulation and Filtration Results (CSU, 1996)

Date/ Pilot Plant Mode	Alum Dose, mg/L	Turbidity, NTU		Log Removals of Organisms and Particles (> 2 μm)					
		Raw	Filt. (Avg.)	Crypto	Giardia	Bacillus	E.Coli	MS2	Particles
Oct 23/I	26	3.27	0.10	3.50	4.50	--	--	--	2.44
Oct 30/I	26	3.23	0.10	--	--	--	--	2.51	0.62
Nov 10/I	26	1.16	0.08	3.20	--	--	--	--	1.91
Nov 29/I	26	1.22	0.08	--	--	2.45	--	--	1.79
Dec 5/I	26	1.07	0.07	3.81	2.92	--	--	2.81	1.84
Dec 12/I	26	1.00	0.08	3.72	3.15	--	--	--	2.04
Dec 19/I	26	1.25	0.08	4.32	3.70	--	--	--	1.89
Jan 15/I	13	1.18	0.53	2.61	1.48	--	--	0.93	--
Feb 5/I	13	1.27	1.08	2.61	1.76	0.58	1.47	--	--
Feb 26/C	26	1.29	0.10	4.22	3.40	--	--	2.23	--
Mar 5/C	26	1.29	0.11	4.34	3.20	--	--	--	2.15
Mar 19/C	26	1.49	0.16	4.34	3.84	2.25	2.91	--	1.83
Apr 2/I	26	1.52	0.09	3.90	3.54	2.55	--	--	2.02
Apr 9/C	26	1.42	0.09	4.95	4.55	--	--	2.73	2.41
May 7/C	26	1.73	0.09	4.19	4.25	--	--	3.50	2.60
May 16/I	26	2.17	0.06	--	--	--	--	3.08	2.61
May 24/I	26	2.29	0.06	4.00	3.86	2.89	2.28	--	2.52
May 28/I	26	2.47	0.07	2.46	2.89	2.69	1.77	3.36	2.40
Jun 4/I	26	2.54	0.07	4.30	3.58	--	3.09	2.81	2.85
Jun 11/I	26	2.64	0.08	3.00	2.85	3.23	2.99	2.79	2.71
Jun 25/I	26	2.72	0.09	3.33	3.14	2.08	3.32	3.01	2.73
Jun 29/I	26	2.71	0.09	2.47	2.86	2.75	2.56	2.85	2.58

NOTES: I = in-line filtration; C = conventional filtration; -- = no data; Jan 15 and Feb 5 runs used suboptimum coagulation; alum used as coagulant; particle count data are for all particles > 2 μm in size

APPENDIX 3C
STATE-SPECIFIC VERIFICATION TESTING REQUIREMENTS

California:

- The coefficient of variation for turbidity of an individual filter run should be restricted to below 15%, to ensure consistent performance between the individual filter runs, and indication of good process control.

Ohio:

- Additional site specific pilot testing may be necessary where seasonal turnover of reservoirs and lakes due to thermal destratification (spring and fall) impacts the chemical and colloidal nature of the turbidity. Non-seasonal testing may not be able to characterize the system's ability to deal with algae blooms.

- Total hardness should be measured at least daily rather than weekly, as specified in this test plan (Table 3).

Virginia:

- Additional site-specific pilot testing will be required whenever the ETV testing does not adequately address seasonal source water quality issues. This is especially likely for verifications based on a single season of testing.
- Measurements of pH and alkalinity should be taken hourly for at least 2 hours following any change in coagulant dose.

CHAPTER 4

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN
BAG FILTERS AND CARTRIDGE FILTERS FOR THE REMOVAL OF MICROBIOLOGICAL AND PARTICULATE CONTAMINANTS

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for evaluation of water treatment equipment utilizing bag filters or cartridge filters. This Testing Plan is to be used as a guide in the development of the Product-Specific Test Plan for testing bag filtration or cartridge filtration equipment, within the structure provided by the document, "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies."

In order to participate in the equipment verification process for bag or cartridge filtration, the equipment Manufacturer shall employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of the Product-Specific Test Plan. The procedures and methods shall generally follow those Tasks related to Verification Testing that are outlined herein, with changes and modifications made for adaptations to specific bag filtration or cartridge filtration equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

- Introduction;
- Objectives;
- Work Plan;
- Analytical Schedule;
- Evaluation Criteria.

Each Product-Specific Test Plan shall include Tasks 1 through 6 as described later in this document.

2.0 INTRODUCTION

This Equipment Verification Testing Plan is applicable to the testing of water treatment equipment utilizing bag filtration equipment or cartridge filtration equipment. Two phases of testing are discussed. The first phase is Initial Operations, which consists of a series of tests that will be used by the Manufacturer to determine the optimum treatment scheme and most appropriate testing schedule at the specific geographical location or locations where testing is carried out. The second phase is Verification Testing, which will evaluate performance of the equipment under different raw water quality conditions. Verification Testing will be done during time periods when the source water or feed water quality is appropriate for testing the full range of water quality conditions that need to be evaluated. Development and execution of well-documented testing covering a wide range of water quality has a better chance of minimizing subsequent on-site testing which states may require before approving use of the equipment at specific locations.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analytical work to be carried out as a part of this Verification Testing Plan will be contracted with a state-certified or third party- or EPA-accredited analytical laboratory.

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the recommended tasks that may be included in Initial Operations and of the required and optional tasks to be included in the bag filtration and cartridge filtration Verification Testing program. Tasks A and B are sequential tasks done before Verification Testing. Tasks 1 through 6 are to be done during Verification Testing and have overlapping time frames.

4.1 Task A: Characterization of Feed Water

The objective of this Initial Operations task is to obtain a chemical, biological and physical characterization of the feed water. A brief description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization.

4.2 Task B: Initial Tests Runs

During Initial Operations, a Manufacturer may choose to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water. During this task, an inspection of field operations and analytical procedures will be carried out. Following the inspection, testing for variability in performance of bags or cartridges shall be undertaken.

4.3 Task 1: Verification Testing Runs

Water treatment equipment shall be operated for a minimum of 30-days during each of one or more testing periods to collect data on equipment performance and water quality for purposes of performance verification.

4.4 Task 2: Feed Water and Finished Water Quality

During each day of Verification Testing, feed water and treated water samples shall be collected, and appropriate sample analysis shall be undertaken. If pre-filtration clarification equipment is used, its effect on water quality shall be documented.

4.5 Task 3: Operating Conditions and Treatment Equipment Performance

During each day of Verification Testing, operating conditions and performance of the water treatment equipment shall be documented including filtration rate and rate of filter head loss gain. If pre-filtration equipment is used, the equipment shall be described, and the operating conditions shall be documented.

4.6 Task 4: Microbiological Contaminant Removal

The objective of this task is to evaluate removal of microbiological contaminants or surrogates during Verification Testing by measuring removal of *Cryptosporidium* oocysts or of protozoan-sized particles seeded in the feed water, or by undertaking a combination of the above techniques.

4.7 Task 5: Data Management

The objectives of this task are to establish an effective field protocol for data management at the field operations site and for data transmission between the Testing Organization and the NSF for data obtained during the Verification Testing and to develop statistical analysis of certain test data.

4.8 Task 6: QA/QC

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during bag filtration or cartridge filtration equipment Verification Testing.

5.0 TESTING PERIODS

The required tasks in the Verification Testing Plan (Tasks 1 through 6) are designed to be carried out over one or more 30-day periods, not including mobilization, start-up, and Initial Operations. Additional verification testing periods may be necessary to verify the manufacturer's objectives, such as in the treatment of surface water where additional testing during each season may assist in verifying an objective. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's objectives. For example, a good challenge for a bag filter or cartridge filter would be a testing period during which the feedwater exhibits the highest turbidity the equipment is capable of handling and/or algal blooms. Although one testing period satisfies the minimum requirement of the ETV Program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined in Initial Operations. Performance and reliability of the equipment shall be tested during verification testing periods at a minimum of 30 days. The purpose of the 30 day minimum test period is to operate the equipment and evaluate the performance under a range of circumstances including installation of new bags or cartridges and attainment of terminal headloss.

A schedule describing the duration and initiation of each of the above tasks is provided in Table 1.

6.0 DEFINITIONS

Definitions that apply for bag filtration and cartridge filtration processes include:

6.1 Bag Filter: A non-rigid, disposable, fabric filter in which flow generally is from the inside of bag to the outside. One or more filter bags are contained within a pressure vessel designed to facilitate rapid change of the filter bags when the filtration capacity has been used up. Bag filters generally do not employ any chemical coagulation, if pretreatment is employed. For these filters, pretreatment is likely to consist of prefiltration or predisinfection. The pore sizes in the filter bags designed for protozoa removal generally are small enough to remove protozoan cysts and oocysts but large enough that bacteria, viruses and fine colloidal clays would pass through.

6.2 Cartridge Filter: A rigid or semi-rigid, disposable, self-supporting filter element in which flow generally is from the outside of the cartridge to the inside. One or more filter cartridges are contained within a pressure vessel designed to facilitate rapid change of the cartridges when the filtration capacity has been used up. Cartridge filters generally do not employ any chemical coagulation, if pretreatment is employed. For these filters, pretreatment is likely to consist of prefiltration or predisinfection. The pore sizes in the filter cartridges designed for protozoa removal generally are small enough to remove protozoan cysts and oocysts but large enough that viruses and fine, sub-micron colloidal clays would pass through.

6.3 Filtration: A process for removing particulate matter from water by passage through porous media.

6.4 Predisinfection: Disinfection done at the beginning of treatment. Some regulatory agencies may require predisinfection to retard microbial growth on the bag or cartridge filters.

6.5 Prefiltration: A first-stage filtration process sometimes used ahead of bag filters or cartridge filters. Prefilters generally do not employ chemical pretreatment, but are instead intended to remove coarser particulate matter, thus prolonging the life of the bag filter or cartridge filter being used to remove protozoan cysts or oocysts.

7.0 TASK A: CHARACTERIZATION OF FEED WATER

7.1 Introduction

This Initial Operations task is needed to determine if the chemical, biological and physical characteristics of the feed water are appropriate for the bag filtration or cartridge filtration equipment to be tested. This task should be undertaken with great care, because of the limited capability of bag filters and cartridge filters to remove fine colloidal clays that cause turbidity in many surface waters and because feed waters having high concentrations of particulate matter such as algae, particles consisting of plant material, or sediment can rapidly clog bag filters and cartridge filters, necessitating replacement of the clogged filters.

If the source water used as feed water for the testing program has an excessive amount of the fine turbidity-causing particles, the bag filtration or cartridge filtration equipment may not be able to attain sufficient turbidity removal. Because bag filters and cartridge filters do not remove viruses, the entire burden of virus control falls on the disinfection process when these filters are used for water treatment. Excessive turbidity in filtered water could present problems in attaining effective disinfection and would be a likely cause for rejection of bag filters or cartridge filters by drinking water regulators.

If the source water used as feed water consistently has a very low turbidity and very low concentration of algae and other particulate matter, drinking water regulators may be reluctant to approve cartridge filters or bag filters for applications in which the source water turbidity or particulate matter concentration is higher (Alaska Department of Environmental Conservation, 1994). The feedwater quality chosen for Verification Testing can influence both performance of the filtration equipment and the potential for acceptance of testing results by state regulatory agencies.

7.2 Objectives

The objective of this task is to obtain data from one or more years for the chemical, biological, and physical characterization of the source water or the feed water that will be entering the treatment system being tested. Factors of particular interest include conditions that affect bag filter and cartridge filter cycle lengths, such as turbidity in runoff events following heavy rainfall or snowmelt, or algae blooms.

7.3 Work Plan

This task can be accomplished by compiling data obtained from third party sources (i.e. USGS, USEPA, State Laboratories, Municipal Laboratories). The specific parameters needed to characterize the water will depend on the equipment being tested but information on the following characteristics should be compiled:

- Turbidity, Algae, Temperature, and pH
- Total Coliform, Total Alkalinity, Hardness, and True Color
- TSS

Sufficient information shall be obtained to illustrate the timing and degree of variations expected to occur in these parameters that will be measured during Verification Testing. This information will be compiled and shared with NSF so NSF and the Testing Organization can determine the adequacy of the data for use as the basis to make decisions on the testing schedule. Failure to adequately characterize the feed water (source water) could result in testing at a site later deemed inappropriate, so the initial characterization will be important to the success of the testing program.

A brief description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization. The watershed description should include a statement of the approximate size of the watershed, a description of the topography (i.e. flat, gently rolling, hilly, mountainous) and a description of the kinds of human activities that take place (i.e. mining, manufacturing, cities or towns, farming) or animal activities with special attention to potential sources of pollution that might influence feed water quality. The nature of the water source, such as stream, river, lake, or man-made reservoir, should be described as well.

7.4 Analytical Schedule

In many cases, sufficient water quality data may already exist to permit making a determination of the suitability of a source water for use as feed water in a bag filtration and cartridge filtration Verification Testing program.

7.5 Evaluation Criteria

Feed water quality will be evaluated in the context of the Manufacturer's statement of performance objectives. If the turbidity of the feed water is substantially greater than 1 nephelometric turbidity unit (ntu) and periodically exceeds 5 ntu, producing filtered water with an acceptable turbidity may be difficult. The feed water should challenge the capabilities of the equipment but should not be beyond the range of water quality suitable for treatment by the equipment in question.

8.0 TASK B: INITIAL TEST RUNS

8.1 Introduction

During Initial Operations, a Manufacturer may choose to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water. This is a recommended portion of the Initial Operations task and may occur during each of the periods in which Verification Testing is to be done. Initial test runs are required before the start of the first period of Verification Testing so an NSF field inspection of equipment operations and sampling and field analysis procedures can be carried out. After the field inspection, simultaneous testing of multiple bags or cartridges is required before the first period of verification testing so performance variability of bags or cartridges within one lot or between manufacturing lots can be evaluated.

8.2 Objectives

One objective of these test runs is to determine the proper approach for treatment of the feedwater during Verification Testing. Treatment requirements may be different for feedwaters from different test sites or for the feedwater from the same site at different times of testing. Therefore, conducting initial test runs for each testing period is strongly recommended. Some source waters used as feedwater may require prefiltration to remove coarse particulate matter, as a means of extending the life of the bag filters or cartridge filters that will be used for the control of microorganisms. Testing may also be needed to demonstrate the level of filtered water turbidity that the equipment can produce at the test site.

A second objective of initial test runs is to operate the equipment as it would be operated during Verification Testing, and to conduct sampling and analysis for purposes of a field inspection.

A third objective is to set up and operate filters to assess variability of filter bags or filter cartridges within one manufacturing lot and among three different manufacturing lots.

8.3 Work Plan

Initial tests for bag filtration and cartridge filtration can be conducted using the filtration equipment that would be used for Verification Testing, so an assessment could be made to determine whether prefiltration might be needed during verification testing. During exploratory tests, filters can be operated until terminal headloss is reached or until sufficient data are collected to facilitate making reliable projections on the total volume of water that could be filtered through a filter bag or cartridge before it clogs and must be replaced.

Before the first period of Verification Testing, simultaneous testing of three filters from the same lot and receiving feed water from a single source, shall be carried out for 10 days. Then the Field Testing Organization shall change out the filter bags or cartridges and replace them with one bag or cartridge from the first lot tested and with two other bags or cartridges from two different lots. Following the change of cartridges or bags, another 10 days of simultaneous testing shall be done with treatment of feed water from a single source. All filters shall be operated at the same rate of flow except for reductions in flow caused by head loss.

During both of the 10 day testing periods, each filter shall be operated for 23 hours and stopped for 1 hour during each of the 10 days of operation. If a filter bag or cartridge fails due to terminal head

loss or turbidity breakthrough, it shall be replaced by another bag or cartridge from the same lot and testing shall continue until the 10 days are concluded.

The testing for water quality shall focus on turbidity and particle counting only, with no microbiological sampling done for detection of differences between bags or cartridges, to obtain data using a sensitive monitoring technique, but at the same time minimizing the monitoring costs. A single particle counter equipped with a portable grab sampler device can obtain continuous samples sequentially from three different filters. In a similar manner, a single flow-trough turbidimeter can be used to sequentially sample filtered water from three filters. Sampling filtered water from each filter for 20 minutes during each hour would provide for collecting one set of data from each filter for each hour during a work day, and this would yield about 80 data points for each filter in a 10 day period. Appropriate statistical analyses shall be carried out to assess the differences in performance among three bags or cartridges of the same lot and among three bags or cartridges from three different lots. Other data collected shall include rate of flow and head loss. Raw water particle count and turbidity data may be helpful in assessing filter performance.

8.4 Analytical Schedule

Because these runs are being conducted to define operating conditions for Verification Testing, a strictly defined schedule for sampling and analysis does not need to be followed. Adhering to the schedule for sampling and analysis to be followed during Verification Testing would be wise, however, so the operator can gain familiarity with the time requirements that will be applicable later on in the test program. Also, during the Initial Operations phase, NSF will be conducting an initial on-site inspection of field operations, sampling activities, and on-site sample analysis. The sampling and analysis schedule for Verification Testing shall be followed during the on-site inspection. In addition, the testing of three filter bags from one lot followed by the testing of three bags from three lots shall not begin until after the on-site inspection of field operations has been conducted and operating procedures, turbidity analysis, and particle counting have been deemed acceptable. During each of the days in which variability testing is done, at least 8 samples of filtered water from each filter shall be analyzed for turbidity and particle count, with sampling from each filter carried out over at least an 8 hour time span.

8.5 Evaluation Criteria

The Manufacturer should evaluate the data produced during the Initial Operations to determine if the water treatment equipment performed so as to meet or exceed expectations based on the statement of performance objectives with regard to water quality. If the performance was not as good as the statement of performance objectives, the Manufacturer may wish to conduct more Initial Operations or to cancel the testing program. In addition, the initial test run results on expected water production per individual filter bag or filter cartridge may provide guidance regarding the need for prefiltration ahead of the bag filtration or cartridge filtration equipment to be operated during Verification Testing.

After the variability testing of multiple bags or cartridges has been completed, the Field Testing Organization shall use the turbidity data and the particle count data collected during the variability testing to calculate 95% confidence intervals as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies." The manufacturer is encouraged to review the variability in performance of bags or cartridges from the same lot and the variability in performance

of bags or cartridges from three different lots. If the variability is so great that both successful performance and performance failures occurred during simultaneous testing of multiple bag or cartridge filters, the manufacturer may wish to consider whether it is appropriate to continue with Verification Testing.

9.0 TASK 1: VERIFICATION TESTING RUNS AND ROUTINE EQUIPMENT OPERATION

9.1 Introduction

Water treatment equipment employing bag filtration or cartridge filtration shall be operated for Verification Testing purposes, with the approach to treatment based on the results of the Initial Operations testing.

9.2 Experimental Objectives

The objective of this task is to operate the treatment equipment provided by the Manufacturer for periods of 30 days or longer and to evaluate equipment performance under a range of circumstances including installation of new bags or cartridges and attainment of terminal head loss.

9.3 Work Plan

9.3.1 Verification Testing Runs

The Verification Testing Runs in this task consist of continued evaluation of the treatment system, using the most successful treatment parameters defined in Initial Operations. To obtain a perspective on the overall performance of the equipment, one or more Verification Testing periods, each lasting for a minimum of 30 days, are anticipated for evaluating the performance of a treatment system. Verification Testing shall be conducted under conditions likely to provide a suitable range of feed water quality for testing purposes. During each testing period, Tasks 1 through 6 shall be conducted simultaneously.

Testing over a range of feed water quality is recommended because of the differences in water quality that occur on a seasonal basis or at different locations. For bag filtration and cartridge filtration treatment equipment, factors that can influence treatment performance include:

- high turbidity, often occurring in spring, encountered in rivers carrying a high sediment load or in surface waters during periods of high runoff resulting from heavy rains or snowmelt
- algae, which may exhibit blooms on a seasonal basis in spring, summer or fall
- lake or reservoir turnover, if this results in bottom sediments being suspended and carried up closer to the surface where they enter the source water (feedwater) intake

It is highly unlikely that all of the above problems would occur in a surface water during a single testing period, and this results in the requirement for multiple testing periods or multiple sites or both to capture critical events that affect water quality.

9.3.2 Routine Equipment Operation

If the water treatment equipment is being used for production of potable water, in the time intervals between verification runs, routine operation for water production is anticipated. In this situation, the operating and water quality data collected and furnished to the SDWA primacy agency shall also be supplied to the NSF-qualified Testing Organization.

9.4 Schedule

During Verification Testing, water treatment equipment shall be operated for a minimum of 30 days. Bag filtration or cartridge filtration treatment equipment shall be operated from start-up until terminal head loss is attained or until the turbidity performance objective of the Manufacturer is not met for 8 hours. During this period of time, the filtration equipment shall be operated for 23 hours and turned off for one hour, for each day after the first day of operation. The one-hour shutdown shall be done to simulate the on-off operating mode that may be encountered in many small systems, while the 23 hours of operation provides the opportunity for the FTO to log close to the maximum number of hours of equipment operation available each day, thus helping to minimize the total number of days of operation needed to attain terminal head loss. When terminal head loss is attained, the clogged bag or cartridge shall be removed and replaced with a new one, and operation shall resume. The duration of each filter run from initial start to filter clogging and the number of gallons of water produced per square foot (or cubic meters of water produced per square meter) of filter area or the volume of water produced by a specified bag or cartridge shall be recorded in the operational results.

During routine equipment operation, the water treatment equipment should be operated in a manner appropriate for the needs of the water system.

9.5 Evaluation Criteria

The goal of this task is to operate the equipment for the 30-day period, including time for changing prefilters or bag or cartridge filters and other necessary operating activities, during Verification Testing. Data shall be provided to substantiate the operation for 30 days or more.

10.0 TASK 2: TEST RUNS FOR FEEDWATER AND FINISHED WATER QUALITY

10.1 Introduction

Surface waters of high quality are the only surface waters appropriate for treatment by bag filtration and cartridge filtration equipment. Characterization of the feed water is very important, as feed water quality can strongly influence the performance of this equipment. Bag filters and cartridge filters function by straining, so a mat or cake builds up on the filter surface and in the pores of the filter medium. If the materials being removed are not compressible, such as hard, mineral materials, the build-up of this cake may not hinder filtration seriously. On the other hand, removal of compressible particles such as algae or fragments of biological matter can cause the filter to become blinded. Because filtration of some types of particles can blind bag and cartridge filters, they are appropriate only for high quality waters. Turbidity of a source water may not be an adequate indicator of its suitability for treatment by these filters. The volume of water that can be filtered could vary by a factor of ten fold or greater for water of a given turbidity, depending on the nature of the particulate

matter in the raw water because turbidity cannot indicate whether particles are compressible or incompressible.

As always in Verification Testing, characterization of the filtered water is very important. Water quality data shall be collected for the feedwater and filtered water as shown in Table 2, during Verification Testing. At a minimum, the required sampling schedule shown in Table 2 shall be observed by the Testing Organization on behalf of the Manufacturer. Water quality goals and target removal goals for the water treatment equipment shall be recorded in the Product-Specific Test Plan in the statement of objectives.

10.2 Experimental Objectives

A list of the minimum number of water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 2. The actual water quality parameters selected for testing shall be stipulated by the Manufacturer in the Product-Specific Test Plan and shall include all those necessary to permit verification of the statement of performance objectives. If the water being filtered tends to cause rapid increases in head loss, efforts should be made to identify the nature of the particulate matter that is causing the rapid clogging. If prefiltration is used, the performance of the prefilter or prefilters with respect to water quality must also be documented. Without such documentation the range of water quality for which bag filtration or cartridge filtration equipment may be accepted could be considerably more restricted.

The characterization of feed water is intended to provide sufficient information to enable State drinking water regulators to compare the quality of the feed water used in Verification Testing with the quality of source water at a site where the use of the equipment may be proposed.

10.3 Work Plan

The manufacturer will be responsible for establishing the filtration equipment operating parameters, on the basis of the initial test runs. The bag filtration or cartridge filtration equipment shall be operated as described in Task 1, Section 9.4, Schedule. If terminal head loss is reached, the filter bag (or bags) or filter cartridge (or cartridges) shall be replaced with new ones, and filtration operations shall be resumed and continued until the end of the 30-day period.

Many of the water quality parameters described in this task will be measured on-site by the Field Testing Organization. Analysis of the remaining water quality parameters will be performed by a state-certified or third party- or EPA-accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field will be described in the Analytical Methods section below and in Table 3. The analytical methods utilized in this study for on-site monitoring of feedwater and filtered water qualities are described in Task 6, Quality Assurance/Quality Control (QA/QC). Where appropriate, the *Standard Methods* reference numbers for water quality parameters are provided for both the field and laboratory analytical procedures. One analytical procedure that is not required but which might prove helpful if excessive clogging of the filters is encountered is the Microscopic Particulate Analysis (MPA) for Filtration Plant Optimization (EPA 910-R-96-001).

10.3.1 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during each period of filtration testing, as noted in this section. Additional sampling and data collection may be performed

at the discretion of the Manufacturer. Sample collection frequency and protocol shall be defined by the Manufacturer in the Product-Specific Test Plan.

In the case of water quality samples that will be shipped to the state-certified or third party- or EPA-accredited analytical laboratory for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the state-certified or third party- or EPA-accredited analytical laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory.

10.4 Analytical Schedule

During Verification Testing for bag filtration and cartridge filtration treatment equipment, the feedwater (raw water) quality and filtered water quality shall be characterized by measurement of the following water quality parameters:

- temperature (daily)
- pH (daily)
- total alkalinity (desired weekly but optional)
- hardness (desired weekly but optional)
- total organic carbon (desired weekly but required only once per test period)
- iron (once per test period if less than 0.3 mg/L, or weekly if 0.3 mg/L or greater in feed water)
- manganese (once per test period if less than 0.05 mg/L, or weekly if 0.05 mg/L or greater in feed water)
- algae, number and species (weekly if no pre-filtration used; three times per week if pre-filtration used; three times per week if the pressure drop [head loss] across the bag filter or cartridge filter increases in one day's time by more than 5 percent of the total head loss initially available)
- UV_{254} absorbance (desired weekly but optional)
- true color (desired weekly but optional)
- total coliform bacteria (desired twice per week but optional)
- turbidity (every four hours or continuous for feedwater; continuous for filtered water; and at shutdowns and startups as described in Section 12.5)
- particle counts (see Task 4)

Any parameter that is part of the Manufacturer's performance objective is not considered optional; the recommended frequency shall be the minimum frequency of sampling. If grab samples are used for feed water turbidity measurements, two samples for feed water turbidity shall be collected during the 30 minutes prior to the one-hour shutdown, and two samples for feed water turbidity shall be collected during the 30 minutes after start-up following the one-hour shutdown.

If prefiltration is done to condition the feed water for treatment by bag filtration or by cartridge filtration, the water discharged from the prefiltration process shall be sampled and the following water quality parameters shall be measured:

- iron (same as above)
- manganese (same as above)
- algae, number and species (three times per week)
- turbidity (continuous)
- particle counts (see Task 4)
- TOC (desired weekly but required only once per test period)
- true color and UV_{254} absorbance (desired weekly but optional)

Turbidity of filtered water shall be measured and recorded using a continuous, flow-through turbidimeter. Turbidity of feed water (before seeding of microorganisms or microspheres) shall be measured continuously using a flow-through turbidimeter or at intervals of not more than four (4) hours if a bench model turbidimeter is used for grab samples. On a daily basis a bench model turbidimeter shall be used to check the continuous turbidimeter readings.

The above water quality parameters are listed to provide verification report readers with background data on the quality of the feed water being treated and data on the quality of the filtered water. These data are to be collected to enhance the usefulness of the Verification Testing data to a wide range of verification report readers.

10.5 Evaluation Criteria

Evaluation of water quality in this task is related to any general water quality capabilities indicated by the Manufacturer.

- Turbidity removal equals or exceeds goals specified by the Manufacturer
- Water quality and removal goals specified by the Manufacturer
- Water quality improvement attained by prefiltration

11.0 TASK 3: DOCUMENTATION OF OPERATING CONDITIONS AND TREATMENT EQUIPMENT PERFORMANCE

11.1 Introduction

During each day of Verification Testing, operating conditions shall be documented. This shall include descriptions of treatment processes used and their operating conditions. In addition, the performance of the water treatment equipment shall be documented, including rate of filter head loss gain, water pressure at the inlet to the bag filter or cartridge filter pressure vessel, length of filter run and terminal head loss. Operating conditions are likely to be evaluated in great detail by state reviewers and are an important aspect related to approval of equipment.

11.2 Objectives

The objective of this task is to accurately and fully document the operating conditions that applied during treatment, and the performance of the equipment. This task is intended to result in data that

describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

11.3 Work Plan

A complete description of each process shall be given. Data on the filter shall be provided and shall include the following:

- flow capacity
- nominal pore rating of filter bag or filter cartridge and the method used to determine this pore rating
- number of filter bags or filter cartridges housed within the pressure vessel
- maximum operating pressure of filter vessel
- volume of filter vessel
- if any pre-filtration equipment is used, a complete description of the pre-filtration equipment shall be provided that conveys the same types of the information required for bag filtration or cartridge filtration equipment.

In addition, system reliability features including redundancy of components, shall be described. Spatial requirements for the equipment (footprint) shall be stated. Some of the above requirements might be met by providing manufacturer's engineering drawings of the equipment used in Verification Testing.

During each day of Verification Testing, treatment equipment operating parameters for bag filtration and cartridge filtration will be monitored and recorded on a routine basis. This shall include rate of flow, filtration rate, pressure at filter vessel inlet and outlet, and maximum head loss. Electrical energy consumed by the treatment equipment shall be measured, or as an alternative, the aggregate horsepower of all motors supplied with the equipment could be used to develop an estimate of the maximum power consumption during operation. Performance shall be evaluated to develop data on the number of gallons of water that are treated by each bag or cartridge and on energy needed for operation of the process train being tested.

A daily log shall be kept in which events in the watershed are noted if they could influence source water quality. This includes such things as major storm systems, rainfall, snowmelt, temperature, cloud cover, upstream construction activities that disturb soil, and intermittent operation of hydroelectric generating facilities.

If prefiltration equipment is used, the performance of that equipment shall be documented in the same manner as the bag filtration or cartridge filtration is documented.

Performance of bag filtration and cartridge filtration for removal of turbidity and microorganisms can be strongly influenced by the pore sizes of the bag filter or the cartridge filter. Therefore the manufacturer's specifications on the bag filter or cartridge filter used when turbidity or microorganism data are gathered shall be identified.

11.4 Schedule

Table 4 presents the schedule for observing and recording bag filtration and cartridge filtration equipment plant operating and performance data.

11.5 Evaluation Criteria

Where applicable, the data developed from this task will be compared to statements of performance objectives. The quantity of water that is produced and meets quality criteria for acceptance will be an important factor in this evaluation.

If no relevant statement of performance capability exists, results of operating and performance data will be tabulated for inclusion in the Verification Report.

12.0 TASK 4: MICROBIOLOGICAL CONTAMINANT REMOVAL

12.1 Introduction

Removal of microbiological contaminants is a primary purpose of filtration of surface waters. Consequently, the effectiveness of bag filtration and cartridge filtration treatment processes for microbial removal will be evaluated in this task. Assessment of treatment efficacy will be made on the basis of particle counting and removal of polymeric microspheres. Testing for removal of protozoan microorganisms is optional.

The bag filtration and cartridge filtration process removes particles, including microorganisms, in the size range of *Giardia* and *Cryptosporidium* from water by physically straining out the particles and trapping them in the bag filter or cartridge filter. Because particle removal is accomplished primarily by straining out particles from water on the basis of the sizes of the particles and of the pores in the filter, the applicability of surrogate particles depends on their size, shape and pliability, rather than on their biological nature. Thus appropriately sized microspheres could be suitable surrogates for protozoan cysts and oocysts. Bag filtration and cartridge filtration equipment now is produced for purposes of removing the smaller *Cryptosporidium* oocysts, so testing for *Giardia* cyst removal is not needed.

Cysts and oocysts are biological particles without hard shells or skeletons, so they are capable of deforming slightly and squeezing through pores that might seem to be small enough to prevent their passage. In addition, the pore sizes for filter bags and filter cartridges is not absolute, and these filters will have some pores that are both larger and some that are smaller than the nominal size. Therefore they do not provide an absolute cutoff for particles at or slightly larger than their nominal size. For these reasons, microspheres used in challenge tests should be close to or slightly smaller than the smallest size for the protozoan organism for which the microspheres are a surrogate.

Removal of turbidity by bag filtration and cartridge filtration is not synonymous with removal of protozoan organisms because turbidity-causing particles can be much smaller than protozoa. This results in bag filters and cartridge filters being able to remove protozoan-sized particles while passing particles in the size range of bacteria, or the micron-sized and sub-micron-sized particles that cause turbidity. Therefore turbidity removal is not a surrogate for protozoan removal in bag filtration and cartridge filtration.

Use of electronic particle counting to assess protozoan removal would be appropriate only for feed waters containing large numbers of particles in the size range of Cryptosporidium. For Cryptosporidium oocyst removal, assessment of particle removal in the size range of 3 to 7 μm would be appropriate. For a general evaluation of particle removal capabilities, total particles in the

1 to 15 μm shall also be counted. If sufficient concentrations of appropriately sized particles are not present in the feed water, use of electronic particle counting may not be capable of demonstrating adequately high log removals and therefore microsphere seeding technique described in Section 12.3.1 must be employed.

12.2 Experimental Objectives

The objective of this task is to evaluate removal of particles and microbiological contaminants during Verification Testing by measuring removal of microorganisms seeded into the feed water or by assessing removal of polystyrene fluorescent microspheres if *Cryptosporidium* oocysts are not seeded into the feed water.

12.3 Work Plan

Task 4 shall consist of particle counting and tests involving seeded *Cryptosporidium* oocysts or seeded microspheres, or of both seeded oocysts and seeded microspheres if the manufacturer chooses to test both.

12.3.1 Seeding Technique

The purpose of this task is evaluation of the bag filter or cartridge filter for microorganism removal, so any seeding of *Cryptosporidium* or microspheres shall be done after the feed water has passed prefiltration equipment and just prior to the entry of the water into the bag filtration or cartridge filtration equipment, unless the prefilter and the bag or cartridge filter are designed and sold as a single system having filters in series. During seeding tests, the concentrated suspension of microspheres or oocysts shall be gently stirred to maintain the particles in suspension. The concentrated microspheres shall be suspended in a solution of distilled or deionized water with 0.01% Tween 20. Before each run with seeded microspheres, the holding vessel shall be washed with hot water and laboratory glassware detergent and thoroughly rinsed with tap water or filtered water. The oocyst suspension shall be kept chilled during seeding. Microspheres or oocysts shall be added to the feed water using a variable speed chemical feed pump. Mixing of seeded particles into the feed water shall be done with an in-line mixer that attains a head loss of about 0.3 to 0.5 feet of water during operation.

In order to show a 3-log reduction of either microspheres or oocysts, it is likely that at least 10^6 microspheres or oocysts would need to be spiked in a challenge test.

12.3.2 Electronic Particle Counting

When an electronic particle counter is used for evaluation of particle removal, particle counts in feed water just before entry into the bag filtration or cartridge filtration equipment shall be measured to determine the concentration of particles before filtration, and particle counts in the filtered water shall be measured. For assessing *Cryptosporidium* oocyst removal and removal of larger organisms, particles in the size range of 3 μm to 7 μm shall be counted. If appropriately sized particles are not present in sufficient densities (concentrations) in the feed water to permit calculation of log removals consistent with the Manufacturer's statement of performance capability, then laboratory enumeration should be done during microsphere

challenge events. For a general evaluation of particle removal capabilities, total particles in the 1 to 15 μm shall also be counted.

12.3.3 Microspheres

Evaluation of microsphere removal shall be conducted by measuring the density (or concentration) of microspheres seeded on a continuous basis in the feed water and then measuring the density (or concentration) of microspheres in the filtered water or by determining the number of microspheres added to the feed water in a slug dose and then measuring the total number of microspheres detected in the filtered water. Microspheres used as surrogates for *Cryptosporidium* oocysts shall be 3 to 6 μm in diameter. Microspheres in this size range can be obtained by ordering batches of microspheres in two or more sizes. At least 50% (by number or count) of the microspheres used in challenge tests must be in the 3 to 4 μm size range. *Cryptosporidium* oocysts are considerably smaller than *Giardia* cysts, and a bag filter or cartridge filter capable of attaining a certain degree of removal for *Cryptosporidium* will attain an equal or greater removal of *Giardia*, based on the filtration mechanism being straining or physical blockage of the passage of particles through the filter when all operating conditions are the same.

The number of microspheres used shall be sufficient to permit calculation of log removals that exceed the removal capability as set forth in the Manufacturer's statement of performance objectives. Recovery of microspheres in filtered water provides data for use in calculating definite removal percentages, in contrast to the practice of reporting removals that exceed a specified value based on the detection limit, which would have to be done when no microspheres are detected in filtered water. For testing involving microscopic enumeration, fluorescent microspheres and an optical microscope equipped with ultraviolet illumination shall be used.

If microspheres are seeded into the feed water on a continuous basis, enumeration of microspheres in feed water and filtered water by optical microscopy shall be required.

Two techniques for analysis of water samples containing fluorescent microspheres may be used. One is the method used by Abbaszadegan et al. (1997) for enumeration of *Giardia* cysts and *Cryptosporidium* oocysts, and the other is the method of Li et al. (1997) which they used for enumeration of microspheres.

If the techniques for microsphere sampling and enumeration are based on the research work of Li *et al.* (1997) which was carried out at the U.S. EPA's research laboratory in Cincinnati, the procedures below shall be followed.

Samples of feed water seeded with microspheres and samples of filtered water shall be filtered through 1 μm pore size, 293 mm diameter polycarbonate membranes. A stainless steel filter manifold shall be used to support the polycarbonate membrane. Volume of water filtered, and the times of initiation and completion of filtration shall be noted. The filter shall be removed from the manifold and placed in a container specified by the analytical laboratory, and refrigerated until shipped to the EPA-accredited analytical laboratory. At the analytical laboratory the microspheres removed from the filter with a laboratory squeegee and by washing with about 200 mL of 0.01% Tween 20. The liquid and particulate matter removed from the membrane shall be concentrated to a volume of between 1 and 10 mL by

means of centrifugation for 10 minutes at 1200 x gravity. The volume of the concentrated suspension shall be recorded. Microspheres shall be enumerated using a hemacytometer under a UV microscope at 400 magnification. A minimum of three hemacytometer counts shall be performed for each sample. The volume of suspension examined in the hemacytometer shall be recorded and used to determine the fraction of the original water sample which was ultimately examined under the microscope.

Standard Methods states that hemacytometer chambers come with detailed manufacturer's instructions concerning calculations and proper usage. *Standard Methods* contains the precaution that disadvantage of hemacytometers is that the sample must have a very high density of objects being counted in order to yield statistically reliable data. Some exploratory tests may be needed to identify appropriate volumes of treated water to filter through the polycarbonate membrane or appropriate densities (concentrations) of microspheres in the seeded feed water, so that reliable statistics can be attained in filtered water analysis. The total number of microspheres counted in the hemacytometer should be between 30 and 300 to obtain good statistical results without counting overwhelming numbers of microspheres.

If the entire flow stream produced by the bag filtration or cartridge filtration equipment can not be filtered through the 293 mm membrane filter for sampling, a measured portion of the total filtered water flow can be sampled as it is produced, or the entire flow of filtered water from a seeding test can be stored in clean vessel and later filtered through the 293 mm membrane filter at a rate of flow suitable for the membrane filter. If an instantaneous slug dose of microspheres is applied and the entire volume of filtered water is saved in a storage vessel for subsequent membrane filtration as the sampling procedure, a volume of filtered water of at least 20 times the volume of the bag filter or cartridge filter pressure vessel shall be filtered through the bag or cartridge filtration equipment and saved for sampling and analysis.

12.3.4 Organisms Employed for Challenge Tests

Microbiological testing, if done, shall be performed by seeding *Cryptosporidium* oocysts into the feed water and by analyzing for the organism in question in the feed water and in the filtered water.

The oocysts shall be used in densities sufficient to permit calculation of at least 3-log removal, and seeding of microorganisms shall begin at start-up of the treatment equipment. The organism feed suspension will be prepared by diluting the organisms to be seeded into dilution water that is distilled or deionized and disinfectant free. The feed reservoir for the organism suspension shall be made of biologically inert material (i.e., not toxic to the organisms in the suspension.) The reservoir will be mixed continuously throughout the experiment and kept packed in ice in a cooler. The seed suspension will be fed into the feedwater using an adjustable rate chemical feed pump. Mixing of this suspension with the feedwater will be accomplished using an in-line static mixer.

The analytical method required to be used for *Cryptosporidium* oocysts are EPA methods 1622/1623. If changes to the *Cryptosporidium* methods are tested, peer reviewed, evaluated by several laboratories, and then accepted by the U.S. EPA or are published by *Standard Methods*, the improved methods should be followed. Refer to www.epa.gov/nerlcwww/index.html for updates.

12.4 Analytical Schedule

12.4.1 Particle Counting

Analysis of feed water samples by electronic particle counters may be measured on a batch or a continuous basis. If batch measurements are made, they shall be made for at least 8 hours each working day during Verification Testing, with samples collected and analyzed at least once each hour. Filtered water analysis shall be done using flow-through particle counters, equipped with recording capability so data can be collected on a 24-hour-per-day basis during Verification Testing.

In addition to the sampling and analysis for particle counts during continuous operation, particle count data shall be obtained for three feed water samples and for three filtered water samples during the last 30 minutes before the daily shutdown occurs. After the filter has been restarted one hour later, filtered water particle count data shall be obtained for six samples collected at five-minute intervals during the first 30 minutes of operation after restart, and then three samples of feed water shall be analyzed for particle counts as soon as practical. The purpose of this sampling and analysis is to evaluate the effect of stop-start operations that are common in small systems.

On days when challenge tests are not carried out, at least eight feed water samples shall be obtained for particle counting and for purposes of comparison with filtered water so calculation of log removal of particles can be done.

12.4.2 Microsphere Samples

Planning a sampling schedule for bag filtration or cartridge filtration equipment may be challenging, as the length of a filter run could exceed the 30 days allotted for intense sampling and analysis called for in Verification Testing runs. If the Initial Test Runs conducted during Task B indicate that evaluating three filter runs during the 30 days of Verification Testing will not be possible because of the long duration of the runs, then three sets of microsphere samples shall be collected at each time when seeding is done during the filter run. This will provide data that can be used for statistical analysis, during each time period when Verification Testing is done.

During each microsphere challenge test run, microspheres shall be seeded for evaluating the performance of a continuously running filter three times during a run: at the start-up of the equipment after a new filter bag or filter cartridge has been installed, near the middle of the run when head loss has approached one half of the recommended terminal head loss, and near the end of the run after head loss has exceeded 90 percent of recommended terminal head loss. In addition, after the seeding challenge and sampling event in the middle of the run has been completed, the filter flow shall be stopped and preparations shall be made for another round of sampling. The filter shall be restarted and sampling shall be done again, to evaluate the effect of stopping and starting a filter that has removed a very large number of microspheres.

The timing for collection of samples shall be different based on whether continuous seeding or slug dose seeding is used. When microspheres are seeded on a continuous basis, microsphere samples shall be collected from the plant influent (feed water after seeding) and

the filter effluent. Samples shall not be collected until the treatment plant has been in operation for a total of 3 theoretical detention times as measured through the filter vessel. For microsphere sampling purposes, the time of operation when 3 filtration vessel detention times have elapsed shall be considered time zero. Four microsphere samples shall be collected, beginning at time zero and at 0.5, 1.0 and 2.0 hours. The exact time of sampling will be recorded so turbidity measurements can be determined at the time of sampling. Volumes of feed water and filtered water to be filtered should be large enough that 30 to 300 microspheres are detected in each seeded feed water sample. Ideally for statistical purposes 30 to 300 microspheres should be detected in each filtered water sample also. If the filtration process is highly efficient for removal of the microspheres, detection of such large numbers in samples of filtered water would not be possible. In such a case, detection of at least 5 microspheres is desirable. If removal is extremely high, detecting 5 or more microspheres in filtered water may not be possible but probably would be indicative of very high log removals of microspheres.

For seeding on a slug dose basis, the number of microspheres in the concentrated suspension shall be based on an analysis of the concentrated suspension before it was dosed. The entire production of filtered water shall be collected for sampling, from the instant of dosing until a volume of filtered water equal to 20 volumes of the filter vessel have been collected. For example, if the filter vessel volume is 40 liters, an 800 liter sample of filtered water shall be collected and then filtered through a membrane filter as described above in the procedure of Li *et al.*

As an alternative to collecting the entire production of filtered water, a side stream of filtered water may be collected for analysis. The entire volume of the side stream shall be filtered through a membrane filter, as described above. This reduces the volume of water that must be filtered through the membrane. In calculation of log removals, the FTO must adjust the number of microspheres seeded into the feed water in proportion to the volume of the side stream as compared to the full flow of the treatment equipment. For instance if the volume of the side stream was only 10 percent of the volume of the full flow treated, the number of microspheres used for calculation of log removals would equal only 10 percent of the total number of microspheres seeded.

Microsphere samples shall be analyzed by an EPA-accredited analytical laboratory.

After the first round of Verification Testing has been done, the results of equipment performance shall be reviewed. If terminal head loss was not approached in the bag filtration or cartridge filtration equipment, it may be desirable to operate the filtration equipment until the filters are approaching terminal head loss and then start another period of Verification Testing with nearly-clogged filters, so challenge testing can be undertaken to evaluate that aspect of filter performance. Failure to do this could cause a serious gap in filter performance data and could have an impact on acceptability of the equipment by state regulators.

12.4.3 Microbiological Samples

Microbiological samples shall be collected from feed water and filtered water on the same schedule stipulated for microsphere samples.

The Field Testing Organization shall then submit collected water samples to an EPA-accredited analytical laboratory for microbial testing.

12.5 Evaluation Criteria

Performance evaluation shall be conducted in a number of ways, depending on the types of data collected during testing.

Performance of bag filtration and cartridge filtration equipment shall be evaluated in the context of the Manufacturer's statement of performance objectives. Turbidity results will be analyzed to determine the percentage of turbidity data in the range of 0.50 NTU or lower, the percentage between 0.51 NTU and 1.0 NTU, the percentage between 1.0 and 5 NTU, and the percentage that exceeded 5 NTU. The time intervals used for determining filtered water turbidity values shall be the same for all data analyzed, and because continuous turbidimeters are to be used to collect turbidity data, the intervals shall be 1/4, 1/2, or 1 hour. In addition, the highest filtered water turbidity observed each day shall be tabulated. The feed water and filtered water turbidity data collected during the 30 minute periods immediately before and following the one-hour shutdowns shall be presented in tables or graphs.

Electronic particle count data shall be evaluated by calculating the change in total particle count from feed water to filtered water, expressing the change as log reduction. The aggregate of particle counting data obtained during each verification testing period shall be analyzed to determine the median log removal and 95th percentile log removal during that verification testing period. Because of possible complications in conducting electronic particle counts on feed water, 1 to 4 hour time intervals shall be used for analysis of particle counting data for log reduction of particles. In addition, particle count data for filtered water shall be presented as time series data showing trends of particle counts with passage of time. Data shall be presented showing particle counts in filtered water at time intervals no longer than one hour for the 30 days of Verification Testing. The feed water and filtered water particle count data collected during the 30 minute periods immediately before and following the one-hour shutdowns shall be presented in tables or graphs.

Data on the density (concentration) of microspheres or protozoa in feed water and filtered water shall be analyzed by the EPA-accredited analytical laboratory to determine the median log removal and 95th percentile log removal during that verification testing period. This analysis shall be done separately for each filter operating condition: at start-up with a new bag or cartridge, mid-way through a run, and after 85 to 95 percent of terminal head loss has been attained.

13.0 TASK 5: DATA MANAGEMENT

13.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software or manual recording methods, or both, for recording operational parameters for the bag filtration or cartridge filtration equipment on a daily basis.

13.2 Experimental Objectives

One objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Testing Organization provides sufficient and reliable operational data for

verification purposes. A second objective is to develop a statistical analysis of the data, as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies."

13.3 Work Plan

13.3.1 Data Management

The following protocol has been developed for data handling and data verification by the Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels will be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data will be manipulated into a convenient framework to allow analysis of equipment operation. Backup of the computer databases to diskette should be performed on a monthly basis at a minimum.

In the case when a SCADA system is not available, field testing operators will record data and calculations by hand in laboratory notebooks. (Daily measurements will be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook will provide carbon copies of each page. The original notebooks will be stored on-site; the carbon copy sheets will be forwarded to the project engineer of the Testing Organization at least once per week. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include a description of the bag filtration and cartridge filtration equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project will be set up in the form of custom-designed spreadsheets. The spreadsheets will be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheet. Data entry will be conducted on-site by the designated field testing operators. All recorded calculations will also be checked at this time. Following data entry, the spreadsheet will be printed out and the print-out will be checked against the handwritten data sheet. Any corrections will be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet will be printed out. Each step of the verification process will be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each filtration test run) will be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA-accredited analytical laboratories, the data will be tracked by use of the same system of run numbers. Data from the outside laboratories will be received and reviewed by the field testing operator. These data will be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

If filter bags or cartridges having different design specifications are used during Verification Testing, each filter bag or cartridge shall be operated for a minimum of 30 days, and the water quality data collected in conjunction with the use of each type of bag or cartridge shall be analyzed and presented separately.

13.3.2 Statistical Analysis

Water quality data developed from grab samples collected during filter runs according to the Analytical Schedule in Task 4 of this Test Plan shall be analyzed for statistical uncertainty. The Testing Organization shall calculate 95% confidence intervals for grab sample data obtained during Verification Testing as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies."

The statistics developed will be helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals. Each of the four conditions described in Task 4 (start of run, middle of run before flow stops, middle of run after flow is stopped and restarted, and near end of run approaching terminal head loss) shall be analyzed separately for 95% confidence intervals. Information on the differences in water quality for the beginning, the middle, and the end of filter runs would be useful in evaluating the effect of installing a new bag or cartridge, and the effect of approaching terminal head loss. Data on microsphere removal in the middle of the run, before and after the filter flow was stopped, can be used to assess the effects of stopping and starting the flow in bag filtration or cartridge filtration equipment.

14.0 TASK 6: QA/QC

14.1 Introduction

Quality assurance and quality control of the operation of the bag filtration and cartridge filtration equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 Work Plan

Equipment flow rates and associated signals should be documented and recorded on a routine basis. A routine daily walk-through during testing will be established to verify that each piece of equipment or instrumentation is operating properly. In-line monitoring equipment such as flow meters, etc. will be checked to confirm that the readout matches with the actual measurement (i.e. flow rate) and that

the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

14.4 Daily QA/QC Verifications

- In-line turbidimeters flowrates (verified volumetrically over a specific time period)
- In-line turbidimeter readings checked against a properly calibrated bench model
- Batch and in-line particle counters flowrates (verified volumetrically over a specific time period).

14.5 QA/QC Verifications Performed Every Two Weeks

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

14.6 QA/QC Verifications for Each Testing Period

- In-line turbidimeters (clean out reservoirs and recalibrate)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)
- Particle counters (perform microsphere calibration verification)

14.7 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of raw water and filtered water quality are described in the section below. In-line equipment is recommended for its ease of operation and because it limits the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. In-line equipment is recommended for measurement of turbidity and for particle counting for feed water and is required for measurement of turbidity and for particle counting for filtered water.

14.7.1 pH

Analysis for pH shall be performed according to *Standard Methods* 4500-H^+. A three-point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

14.7.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Methods* 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1^{o}C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology

(NIST). (A thermometer having a range of -1°C to +51°C, subdivided in 0.1° increments, would be appropriate for this work.)

14.7.3 Color (Optional Parameter)

True color shall be measured with a spectrophotometer at 455 nm, using a Hach Company adaptation of the *Standard Methods* 2120 procedure. Samples shall be collected in clean plastic or glass bottles and analyzed as soon after collection as possible. If samples can not be analyzed immediately they shall be stored at 4°C for up to 24 hours, and then warmed to room temperature before analysis. The filtration system described in *Standard Methods* 2120 C shall be used, and results should be expressed in terms of PtCo color units.

14.7.4 Turbidity Analysis

Turbidity analyses shall be performed according to *Standard Methods* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters shall be used for measurement of turbidity in the filtrate waters, and either an in-line or bench-top may be used for measurement of the feedwater.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring equipment.

14.7.4.1 Bench-Top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of equipment operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples that cause the vial to fog preventing accurate readings, allow the vial to warm up by submersing partially into a warm water bath for approximately 30 seconds.

14.7.4.2 In-Line Turbidimeters. In-line turbidimeters are required for filtered water monitoring during verification testing and must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow rate should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

14.7.5 Particle Counting

In-line particle counters shall be employed for measurement of particle concentrations in filtrate waters. However, either a bench-top or an in-line particle counter may be used to measure particle concentrations in the feedwater, concentrate (where applicable) and pretreated waters (where applicable). Laser light scattering or light blocking instruments are recommended for particle counting during verification testing. However, other types of counters such as Coulter counters or Elzone counters may be considered for use if they can be configured to provide continuous, in-line monitoring for the filtrate product water stream. The following discussion of operation and maintenance applies primarily for use of laser light blocking instruments.

The following particle size ranges (as recommended by the AWWARF Task Force) shall be monitored by both in-line and bench-top analytical instruments during the verification testing:

- 2-3 μm
- 3-5 μm
- 5-7 μm
- 7-10 μm
- 10-15 μm
- > 15 μm

The Field Testing Organization shall be required to document any problems experienced with the monitoring particle counting instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

Use of particle counting to characterize feedwater and filtered water quality is required as one surrogate method for evaluation of microbiological contaminant removal.

14.7.5.1 Bench-Top Particle Counters. All particle counting shall be performed on-site. The particle sensor selected must be capable of measuring particles as small as 2 μm. There should be less than a ten percent coincidence error for any one measurement.

Calibration. Calibration of the particle counter is generally performed by the instrument manufacturer. The calibration data will be provided by the manufacturer for entry into the software calibration program. Once the data has been entered it should be verified using

calibrated commercially-available particle standards or methods. This calibration should be verified at the beginning of each Verification Testing period.

Maintenance. The need for routine cleaning of the sensor cell is typically indicated by: 1) illumination of the sensor's "cell" or "laser" lamps, 2) an increase in sampling time from measurement to measurement, or 3) an increase in particle counts from measurement to measurement. During the ETV testing, the sensor's "cell" and "laser" lamps and the sampling time will be checked periodically. The number of particles in the "particle-free water" will also be monitored daily.

Particle-Free Water System. "Particle-free water" (PFW) will be used for final glassware rinsing, dilution water, and blank water. This water will consist of de-ionized (DI) water that has passed through a 0.22-μm cartridge filtration system. This water is expected to contain fewer than 10 total particles per mL, as quantified by the on-site particle counter.

Glassware Preparation. All glassware used for particle counting samples shall consist of beakers designed specifically for the instrument being used. Glassware will be cleaned after every use by hand washing using hot water and laboratory glassware detergent solution followed by a triple PFW rinse. Sample beakers will then be stored inverted.

Dedicated beakers will be used at all times for unfiltered water, diluted unfiltered water, prefiltered water (if prefiltration is used), filtered water, and PFW. When several samples are collected from various equipment sampling points during one day, the appropriate beakers will be hand-washed as described above, and then rinsed three times with sample prior to collection.

Other materials in contact with the samples, including volumetric pipettes, volumetric flasks, and other glassware used for dilution, will also be triple-rinsed with both PFW and sample between each measurement.

Sample Collection. Beakers should be rinsed with the sample at least three times prior to sample collection for particle counting. Sample taps should be opened slowly prior to sampling. Sudden changes in the velocity of flow through the sampling taps should be avoided immediately prior to sample collection to avoid scouring of particles from interior surfaces. A slow, steady flow rate from the sample tap will be established and maintained for at least one minute prior to sample collection. The sample will be collected by allowing the sample water to flow down the side of the flask or beaker; thereby minimizing entrainment of air bubbles.

Dilution. The number of particles in the raw and pretreated waters (where applicable) is likely to exceed the coincidence limit of the sensor. If so, these samples will be diluted prior to analysis. In all cases, PFW will be used as dilution water.

When necessary, dilutions will be performed as follows:

- Dilution water will be dispensed directly into a 500-mL volumetric flask;
- A volumetric pipette (i.e. 10-mL for a 50:1 dilution) will be used to collect an aliquot of the sample to be diluted (stock);
- The appropriate volume of the stock will be slowly added to the volumetric flask containing the dilution water;
- The volumetric flask will be slowly filled to the full-volume etch with dilution water;
- The volumetric flask will be inverted gently and then its contents will be poured slowly into the appropriate 500-mL flask for analysis.

During each of the above steps, care will be taken to avoid entrainment of air bubbles; thus, samples and dilution water will flow slowly down the side of containers to which they are added. Excessive flow rates through pipette tips, which can cause particle break-up, will be avoided by use of wide-mouth pipettes. Sample water will be drawn into and out of pipettes slowly to further minimize particle break-up.

$$Sample\,Particle\,Concentration = \frac{\{MP - (1 - X) \times PF\}}{X}$$

Actual particle counts in a size range for diluted samples will be calculated based on the following formula:
where MP is the measured particle concentration (particles per mL) in the diluted sample, PF is the measured particle concentration (particles per mL) in the particle-free water, and X represents the dilution factor. For a 25:1 dilution, the dilution factor would be 1/25, or 0.04. The expression for the dilution factor is provided by the following equation:

$$Dilution\,Factor = X = \frac{Volume\,Sample}{Addition\,of\,Volume\,Sample + Volume\,Dilution\,Water}$$

Particle Counting Sample Analysis. To collect samples for particle counting, at least 200 mL of each water sample to be counted (diluted or not) should be collected in the appropriate beaker. The beaker will be placed into the pressure cell and counting will take place in the "auto" mode of the instrument. Four counts will be made of each sample. The first count will serve to rinse the instrument with the sample; data from this count are discarded. Data from the subsequent three counts will be averaged, and the average value will be reported as the count for that sample.

14.7.5.2 In-Line Particle Counters. Any in-line particle sensors selected for use must have capabilities for measurement of particles as small as 2 μm and have a coincidence error of less than ten percent. The particle counter manufacturer shall provide data and methods that the in-line particle sensors meet these criteria or an independent third party shall verify the in-line particle sensor meets the above criteria. The particle counter manufacturer shall provide the methods for demonstration of coincidence error.

The sensors of the in-line units must also be provided with a recent (two months before the start of testing) manufacturer calibration. The calibration shall be verified by measurement of the individual and cocktail suspensions of the monospheres as described for the batch counter; however, in this case the samples must be fed in-line to the counters.

No dilution of the filtered water samples will be conducted. The data acquired from the counters will be electronically transferred to the data acquisition system. If it is known that a particular sensor will not be used for a period of several days or more, refer to the manufacturer recommendations for an appropriate storage protocol.

14.8 Chemical and Biological Samples Shipped Off-Site for Analyses

14.8.1 Organic Parameter: Total Organic Carbon and UV_{254} Absorbance (UV is an Optional Parameter)

Samples for analysis of TOC and UV_{254} absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held, and shipped in accordance with Standard Method 5010B. Storage time before analysis shall be minimized, according to *Standard Methods*. TOC is a required sampling parameter. UV_{254} absorbance is an optional sampling parameter.

14.8.2 Microbial Parameters: Total Coliform (Optional) and Algae

Samples for analysis of total coliform (TC) shall be collected in bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped with an internal cooler temperature of approximately 4°C to the analytical laboratory. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited analytical laboratory within the time specified for the relevant analytical method. The laboratory shall keep the samples at approximately 4°C until initiation of analysis. TC densities shall be reported as most probable number per 100 mL (MPN/100 mL) or as total coliform densities per 100 mL. TC is an optional sampling parameter.

Algae samples shall be preserved with Lugol's solution after collection, stored and shipped in a cooler at a temperature of approximately 4°C, and held at that temperature range until counted.

14.8.3 Inorganic Samples

Inorganic chemical samples, including, alkalinity, hardness, iron, and manganese, shall be collected, preserved and held in accordance with *Standard Methods* 3010B, paying particular attention to the sources of contamination as outlined in Standard Method 3010C. The samples shall be refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C during shipment. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

14.9 Microspheres

The membrane filters used for obtaining microsphere samples shall be refrigerated at approximately 2 to 8°C immediately upon collection. Such samples shall be shipped in a cooler and maintained at a temperature of approximately 2 to 8°C during shipment and in the analytical laboratory, until they are analyzed. This is done to minimize microbiological growth on the membranes.

Recovery of microspheres from suspensions held in glassware shall be evaluated by preparing a suspension of microspheres in which the number of microspheres used to make the suspension is estimated, based on either the weight of dry microspheres or the volume of microspheres in liquid suspension as provided by the supplier. After the suspension is prepared and mixed until it is homogeneous, five aliquots shall be taken and counted in the hemacytometer. After the microsphere density (concentration) has been calculated, aliquots of the suspension shall be diluted and filtered through polycarbonate membrane filters having 1 μm pore size. The elution and concentration steps described in Task 4 shall be followed, and the microspheres shall be counted in a hemacytometer. This shall be done five times, so that statistics can be developed on the recovery of microspheres in the sampling procedure.

As a check on possible interference from fluorescing organisms in the feed water, during each Verification Testing run in which fluorescent microspheres are used, a sample of feed water with no seeded microspheres shall be filtered through a polycarbonate membrane, and the particulate matter on the membrane shall be concentrated using the procedures for microsphere analysis, and the concentrate shall be examined in a hemacytometer by microscope, with UV illumination. If no objects of the size and shape of the microspheres are seen to fluoresce, displaying the same color as the microspheres, then fluorescent objects of the proper color seen in samples with seeded microspheres can be considered to be microspheres.

Microspheres may adhere to surfaces of tanks, vessels, and glassware. All glassware, holding tanks, and membrane filter manifolds must be cleaned between seeding events or sampling events.

15.0 OPERATION & MAINTENANCE

The Field Testing Organization shall obtain the Manufacturer-supplied O&M manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for O&M Manuals for equipment employing bag filters and cartridge filters.

15.1 Maintenance

The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- valves
- pressure filter vessel opening mechanisms
- instruments, such as turbidimeters
- water meters, if provided

The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- tanks and basins
- filter vessels

If prefiltration equipment is used, the manufacturer should provide the same sort of information for that equipment as the information described above.

15.2 Operation

The manufacturer should provide readily understood recommendations for procedures related to proper operation of the equipment, both for filtration equipment and for prefiltration equipment, if that also is used. Among the operating aspects that should be discussed are:

Filtration:

- control of filtration rate
- observation and measurement of head loss during filter run

Filter medium (bag or cartridge) replacement:

- criteria for determining end of filter run
- technique for removal of used filter bag or cartridge
- cleaning of filter vessel, if needed
- procedure for installation of new bag or cartridge
- does manufacturer recommend a technique for confirming proper fit and seal of bag or cartridge after installation and before use to treat water?

Monitoring and observing operation:

- filter vessel inlet pressure
- filter vessel outlet pressure
- raw water turbidity
- filtered water turbidity
- rate of flow
- what to do if turbidity breakthrough occurs

The manufacturer should provide a troubleshooting guide for filtration equipment and for prefiltration equipment, if the latter was also provided. The guide should be a simple check-list of what to do for a variety of problems including:

- loss of raw water (feed water) flow to plant during a filter run
- can't control rate of flow of water through equipment
- no reading on turbidimeter
- newly installed bag or cartridge not seated or fit properly
- filtered water turbidity too high
- filter head loss builds up excessively rapidly
- no head loss readings
- valve stuck or won't operate
- clogged prefiltration equipment (if used)

The following are recommendations regarding operability aspects of equipment employing bag filters or cartridge filters. These aspects of plant operation should be included if possible in reviews of

historical data, and should be included to the extent practical in reports of equipment testing when the testing is done under the ETV Program.

During Verification Testing and during compilation of historical equipment operating data, attention shall be given to equipment operability aspects. If prefiltration equipment is also used, operability of that equipment shall also be discussed. Among the factors that should be considered are:

- can both influent pressure and effluent pressure be measured at filter vessel?
- is rate of flow of raw (feed) water measured?
- can raw (feed) water turbidity be measured continuously?
- can filtered water turbidity be measured continuously?
- can spent filter bags or cartridges be replaced easily and without contamination of filter vessel?
- does operator have a simple, reliable way of knowing the new filter bag or cartridge is installed and seated properly in the filter vessel?
- comment on operability of filtration equipment with and without use of prefiltration equipment, if filtration equipment was operated in both modes
- susceptibility of prefiltration equipment to clogging

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Task 3: Documentation of Operating Conditions and Treatment Equipment Performance, in the Test Plan for Bag Filters and Cartridge Filters.

16.0 REFERENCES

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Table 1. Generic Schedule for Verification Testing		
Testing Period	Initial Operations, Estimated Time	Verification Testing, Minimum Time
Testing Period #1 - Required	1 - 6 weeks	30 days
Testing Period #2 - Optional	1 - 3 weeks	30 days
Testing Period #3 - Optional	1 - 3 weeks	30 days
Testing Period #4 - Optional	1 - 3 weeks	30 days

Table 2. Water Quality Sampling and Measurement Schedule	
Sample or Measure For:	Minimum Frequency:
Temperature	Daily
pH	Daily
Total alkalinity	Desired weekly but optional
Hardness	Desired weekly but optional
Total organic carbon	Desired weekly but required only once per test period
Turbidity grab samples	Every four hours at bench to check continuous turbidimeters and at shutdown and restart
Continuous turbidity monitoring	Use data at 1/4, 1/2, or 1 hour for calculations of long-term performance. Also note maximum turbidity observed each day. Separate analysis for shutdowns and restarts.
Iron	Once each testing period or weekly if present in concentration of 0.3 mg/L or greater
Manganese	Once each testing period or weekly if present in concentration of 0.05 mg/L or greater
Total coliform bacteria	Desired twice per week but optional
Algae, number and species	Weekly if no prefiltration used; three times per week if prefiltration used; three times per week if pressure across bag filter or cartridge filter increases by more than five percent of total allowable pressure increase in one day's time.
UV_{254} absorbance	Desired weekly but optional
True color	Desired weekly but optional
For schedule for microspheres, particle counting, and *Cryptosporidium*, see Task 4.	

Table 3. Analytical Methods			
Parameter	Facility	*Standard Methods*[1] number or Other Method Reference	EPA Method[2]
Temperature	On-Site	2550 B	
pH	On-Site	4500-H^+ B	150.1 / 150.2
Total alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Total organic carbon	Lab	5310 C	
Turbidity	On-Site	2130 B / Method 2	180.1
Particle counts (electronic)	On-Site	Manufacturer	
Iron	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Manganese	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Algae, number and species	Lab	10200 and 10900	
True color	On-Site	Hach Company adaptation of *Standard Methods* 2120	
UV_{254} absorbance	Lab	5910 B	
Total coliform	Lab	9221 / 9222 / 9223	
Cryptosporidium	Lab	NSF and EPA may consider alternative methods if sufficient data on precision, accuracy, and comparative studies are available for alternative methods.	EPA 1622, EPA 1623
Microsphere counts	Lab	Li *et al.*, 1995	

Notes:
1) *Standard Methods* Source: 20th Edition of *Standard Methods* for the Examination of Water and Wastewater, 1999, American Water Works Association.
2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Table 4. Cartridge Filtration and Bag Filtration Equipment Operating Data	
Operating Data	Action
Feedwater Flow and Filter Flow	Check and record twice per day, adjust when >10% above or below goal. Record both before and after adjustment.
Filter Head Loss (filter inlet pressure and filter outlet pressure)	Record initial clean bed total head loss at start of filter run and record total head loss two times per day. Also record this separately for the prefilter if a prefilter is used.
Filtered Water Production	Record gallons or cubic meters of water produced per filter bag or filter cartridge for each filter run, and total water produced by the filtration equipment each day it is operated.
Bag or Cartridge Replacement	Record date and time for replacement, and total gallons or cubic meters of water treated before replacement, and the reason for replacement, such as terminal head loss or excessive filtered water turbidity.
Electric Power	Record meter reading once per day.
Hours operated per day	Record in log book at end of day or at beginning of first shift on the following work day. (Around-the-clock operation is recommended).

CHAPTER 5

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN
PRECOAT FILTRATION FOR THE REMOVAL OF MICROBIOLOGICAL AND PARTICULATE CONTAMINANTS

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for evaluation of water treatment equipment utilizing precoat filtration. This Testing Plan is to be used as a guide in the development of the Product-Specific Test Plan for testing precoat filtration equipment, within the structure provided by the document, "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies."

In order to participate in the equipment verification process for precoat filtration, the equipment Manufacturer shall employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of the Product-Specific Test Plan. The procedures and methods shall generally follow those Tasks related to Verification Testing that are outlined herein, with changes and modifications made for adaptations to specific precoat filtration equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

- Introduction;
- Objectives;
- Work Plan;
- Analytical Schedule;
- Evaluation Criteria.

Each Product-Specific Test Plan shall include Tasks 1 through 6 as described later in this document.

2.0 INTRODUCTION

Water treatment equipment employing precoat filtration is used for a variety of applications, including removal of turbidity from surface waters, removal of *Giardia* and *Cryptosporidium*, and removal of algae from surface waters. Clarification processes generally are not used to pretreat water at precoat filtration plants.

This Equipment Verification Testing Plan is applicable to the testing of water treatment equipment utilizing a precoat filtration process train. Two phases of testing are discussed. The first phase is Initial Operations, which consists of a series of tests that will be used by the Manufacturer to determine the optimum treatment scheme and most appropriate testing schedule at the specific geographical location or locations where testing is carried out. The second phase is Verification Testing, which will evaluate performance of the equipment under different raw water quality conditions. Verification Testing will be done for one or more relatively short time intervals during time periods when the source water or feed water quality is appropriate for testing the full range of water quality conditions that need to be evaluated. Development and execution of well-documented testing covering a wide range of water quality conditions has a better chance of minimizing subsequent on-site testing which states may require before approving use of the equipment at specific locations.

As described in AWWA Manual M30 (AWWA, 1995), "In precoat filtration, unclarified water containing foreign particles is forced, under pressure or by vacuum, through a uniform layer of filtering material (media) that has been deposited (precoated) on a septum. The septum is a permeable support for the media and is sustained by the structure of the filter element. As the water

passes through the filter media and septum, suspended particles about 2 μm and larger are captured and removed." (Unclarified water refers to feed water in the context of this ETV Test Plan.) Types of filter media used in precoat filtration are diatomaceous earth (sometimes referred to as diatomite) and perlite. Of these, diatomaceous earth is used more commonly in treatment of drinking water.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analytical work to be carried out as a part of this Verification Testing Plan will be contracted with a state-certified or third party- or EPA-accredited laboratory.

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the recommended tasks that may be included in Initial Operations and of the required and optional tasks to be included in the precoat filtration Verification Testing program. Tasks A and B are sequential tasks done before Verification Testing. Tasks 1 through 6 are to be done during Verification Testing and have overlapping time frames.

4.1 Task A: Characterization of Feed Water

The objective of this Initial Operations task is to obtain a chemical, biological and physical characterization of the feed water. A brief description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization.

4.2 Task B: Initial Tests Runs

During Initial Operations, a Manufacturer may want to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water. This is a recommended Initial Operations task.

4.3 Task 1: Verification Testing Runs

Water treatment equipment shall be operated for a 272 hour period, or longer, during one or more testing periods to collect data on equipment performance and water quality for purposes of performance verification.

4.4 Task 2: Feed Water and Finished Water Quality

During each day of Verification Testing, feed water and treated water samples shall be collected, and appropriate sample analysis shall be undertaken.

4.5 Task 3: Operating Conditions and Treatment Equipment Performance

During each day of Verification Testing, operating conditions and performance of the water treatment equipment shall be documented. Operating conditions include precoating, body feed,

filtration rate, and method of cleaning filter septum. Equipment performance includes rate of filter head loss gain and length of filter run.

4.6 Task 4: Microbiological Contaminant Removal

The objective of this task is to evaluate removal of microbiological contaminants or surrogates during Verification Testing by measuring removal of microorganisms naturally present in the feed water or by evaluating removal of bacteria, viruses, or protozoan-sized particles seeded in the feed water, or by undertaking a combination of the above techniques.

4.7 Task 5: Data Management

The objectives of this task are to establish an effective field protocol for data management at the field operations site and for data transmission between the Testing Organization and NSF for data obtained during the Verification Testing and to develop statistical analyses of certain test data.

4.8 Task 6: QA/QC

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during precoat filtration equipment Verification Testing.

5.0 TESTING PERIODS

The required tasks in the Verification Testing Plan (Tasks 1 through 6) are designed to be carried out over one or more 272 hour periods, not including mobilization, start-up, and Initial Operations.

A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary to verify the manufacturer's objectives, such as in the treatment of surface water where additional testing during each season may assist in verifying an objective. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's objectives. For example this may include water having high turbidity or turbidity consisting of sub-micron particulate matter, cold water with high content of dissolved oxygen, or source water in which an algae bloom is occurring. Although one testing period satisfies the minimum requirement of the ETV Program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined in Initial Operations. Performance and reliability of the equipment shall be tested during verification testing periods at a minimum of 272-hour periods. The purposes of the 272-hour test period are to: 1) provide opportunity for treatment of feed water having variable quality; 2) provide a data base on multiple filter runs from precoat and start-up to completion of run and cleaning of filter septa prior to precoating for a new filter run, so data can be subjected to statistical analysis (Data from multiple runs are needed for rate of head loss accumulation, total water production during a filter run, filter aid usage, and filtered water quality.); and 3) provide data demonstrating repeatability and dependability of the treatment process over time.

A schedule describing the duration and initiation of each of the above tasks is provided in Table 1.

6.0 DEFINITIONS

Definitions that apply for precoat filtration processes and that were given in the Surface Water Treatment Rule, as published in the *Federal Register* on June 29, 1989, are:

6.1 Diatomaceous Earth Filtration: A process resulting in substantial particulate removal in which (1) a cake of precoat filter media is deposited on a support membrane (septum), and (2) while the water is filtered by passing through the cake on the septum, additional filter media known as body feed is continuously added to the feed water to maintain the permeability of the filter cake.

6.2 Filtration: A process for removing particulate matter from water by passage through porous media.

7.0 TASK A: CHARACTERIZATION OF FEED WATER

7.1 Introduction

This Initial Operations task is needed to determine if the chemical, biological and physical characteristics of the feed water are appropriate for the water treatment equipment to be tested. Information from this task will be of value in selecting a testing site as well as in identifying times when source water quality may appropriately challenge the filtration equipment.

7.2 Objectives

The objective of this task is to obtain a complete chemical, biological, and physical characterization of the source water or the feed water that will be entering the treatment system being tested. Factors of particular interest include conditions that could affect precoat filtration performance, such as turbidity in runoff events following heavy rainfall or snowfall, and algae blooms.

7.3 Work Plan

This task can be accomplished by using analytical measurements obtained from third party sources (i.e. USGS, USEPA, State Laboratories, Municipal Laboratories). The specific parameters needed to characterize the water will depend on the equipment being tested but information on the following characteristics should be compiled:

- Water Temperature, pH, Turbidity, Iron, and Manganese
- Total Alkalinity and Total Hardness
- Total Coliform, *Bacillus* spores, and Algae

Sufficient information shall be obtained to illustrate the timing and degree of variations expected to occur in these parameters that will be measured during Verification Testing for a typical annual cycle for the water source if all testing is done at a single site. This information will be compiled and shared with NSF so NSF and the Testing Organization can determine the adequacy of the data for use

as the basis to make decisions on the testing schedule. Failure to adequately characterize the feed water (source water) could result in testing at a site later deemed inappropriate, so the initial characterization will be important to the success of the testing program.

A brief description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization. The watershed description should include a statement of the approximate size of the watershed, a description of the topography (i.e. flat, gently rolling, hilly, mountainous) and a description of the kinds of human activities that take place (i.e. mining, manufacturing, cities or towns, farming), or animal activities, with special attention to potential sources of pollution that might influence feed water quality. The nature of the water source, such as stream, river, lake, or man-made reservoir, should be described as well.

7.4 Analytical Schedule

In many cases, sufficient water quality data may already exist to permit making a determination of the suitability of a source water for use as feed water in a precoat filtration Verification Testing program.

7.5 Evaluation Criteria

Feed water quality will be evaluated in the context of the Manufacturer's statement of performance objectives. The feed water should challenge the capabilities of the equipment but should not be beyond the range of water quality suitable for treatment by the equipment in question.

8.0 TASK B: INITIAL TEST RUNS

8.1 Introduction

During Initial Operations, a Manufacturer may want to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water. This is a recommended Initial Operations task and may occur during each of the periods in which Verification Testing is to be done. Initial test runs are required before the start of the first period of Verification Testing so an NSF field inspection of equipment operations and sampling and field analysis procedures can be carried out during the initial test runs.

8.2 Objectives

The objective of these test runs is to determine the proper approach for treatment of the feedwater during Verification Testing. Treatment requirements may be different for feedwaters from different test sites or for the feedwater from the same site at different times of testing. Therefore, conducting initial test runs is strongly recommended.

8.3 Work Plan

Initial tests for precoat filtration can be conducted using 0.1 m^2 test filters or precoat filtration equipment. Exploratory tests would be used to evaluate the efficacy of different grades of diatomaceous earth or perlite used as precoat or body feed. Exploratory tests also can be used to evaluate appropriate concentrations of body feed diatomaceous earth or perlite concentration, for selection of a body feed concentration that gives filter runs of appropriate duration. If a pressure

filter is used, exploratory tests could be conducted to ascertain the economical upper bound for pressure drop through the filter at termination of the run. (Higher pressure drop across the filter gives longer filter runs and saves on the cost of diatomaceous earth or perlite for precoating and body feed, but if water is pumped through the filter, the higher pressure drop entails greater energy costs for pumping.) The American Water Works Association's Manual M30, "Precoat Filtration," (AWWA, 1995) contains a chapter giving general concepts of precoat filtration and demonstrating the effect of body feed on total diatomaceous earth or perlite usage.

During exploratory tests, filters can be operated until either terminal headloss is reached or effluent turbidity increases above 1.0 NTU or a value set by the Manufacturer, whichever is lower.

8.4 Analytical Schedule

Because these runs are being conducted to define operating conditions for Verification Testing, a strictly defined schedule for sampling and analysis does not need to be followed. Adhering to the schedule for sampling and analysis to be followed during Verification Testing would be wise, however, so the operator can gain familiarity with the time requirements that will be applicable later on in the test program. Also, during the Initial Operations phase, NSF will be conducting an initial on-site inspection of field operations, sampling activities, and on-site sample analysis. The sampling and analysis schedule for Verification Testing shall be followed during the on-site inspection.

8.5 Evaluation Criteria

The Manufacturer should evaluate the data produced during the Initial Operations to determine if the water treatment equipment performed so as to meet or exceed expectations based on the statement of performance objectives. If the performance was not as good as the statement of performance objectives, the Manufacturer may wish to conduct more Initial Operations or to cancel the testing program.

9.0 TASK 1: VERIFICATION TESTING RUNS AND ROUTINE EQUIPMENT OPERATION

9.1 Introduction

Water treatment equipment employing precoat filtration shall be operated for Verification Testing purposes, with the approach to treatment based on the results of the Initial Operations testing.

9.2 Experimental Objectives

The objective of this task is to operate the treatment equipment provided by the Manufacturer and to assess its ability to meet the water quality goals and any other performance characteristics specified by the Manufacturer in the statement of performance objectives.

9.3 Work Plan

9.3.1 Verification Testing Runs

The Verification Testing Runs in this task consist of continued evaluation of the treatment system, using the most successful treatment parameters defined in Initial Operations. To obtain a perspective on the overall performance of the equipment, one or more Verification Testing periods, each lasting for a minimum of 272 hours (this could consist of 9 full days plus 2/3 day at the beginning and 2/3 day at the end of the testing period), are anticipated for evaluating the performance of a treatment system. Verification Testing shall be conducted under conditions likely to provide a suitable range of feed water quality for testing purposes. During each testing period, Tasks 1 through 6 shall be conducted simultaneously.

Testing over a range of feed water quality is recommended because of the differences in water quality that occur on a seasonal basis. For precoat filtration treatment equipment, factors that can influence treatment performance include:

- high turbidity, often occurring in spring, encountered in rivers carrying a high sediment load or in surface waters during periods of high runoff resulting from heavy rains or snowmelt
- algae, which may exhibit blooms on a seasonal basis
- high dissolved oxygen content, which can affect operation of vacuum precoat filters

It is highly unlikely that all of the above problems would occur in a surface water during a single testing period, and this results in the recommendation for multiple testing periods or multiple sites or both to capture critical events that affect water quality.

9.3.2 Routine Equipment Operation

If the water treatment equipment is being used for production of potable water, in the time intervals between verification runs, routine operation for water production is anticipated. In this situation, the operating and water quality data collected and furnished to the SDWA primacy agency shall also be supplied to the NSF-qualified Testing Organization.

9.4 Schedule

During Verification Testing, water treatment equipment shall be operated continuously for a minimum of 272 hours with interruptions in filtration as needed for cleaning and precoating the filter or for other necessary equipment operations. Precoat filtration treatment equipment shall be operated from start-up until turbidity breakthrough or terminal head loss (as defined by the manufacturer) is attained, at which time the spent diatomaceous earth or perlite filter cake shall be removed, the filter cleaned and precoated, and operation shall resume. Filter runs shall not be stopped before turbidity breakthrough or terminal head loss except because of equipment failure or power interruption, because data on complete filter runs are needed to fulfill the objectives of Verification Testing. The duration of each filter run and the number of gallons of water produced per square foot (or cubic meters per square meter) of filter area shall be recorded in the operational results.

During routine equipment operation, the water treatment equipment should be operated in a manner appropriate for the needs of the water system.

9.5 Evaluation Criteria

The goal of this task is to operate the equipment for the 272 hour period, including time for filter cleaning and precoating as well as and other necessary operating activities, during Verification Testing. Data shall be provided to substantiate the operation for 272 hours or more.

10.0 TASK 2: TEST RUNS FOR FEEDWATER AND FINISHED WATER QUALITY

10.1 Introduction

Water quality data shall be collected for the feedwater and filtered water as shown in Table 2, during Verification Testing. At a minimum, the required sampling schedule shown in Table 2 shall be observed by the Testing Organization on behalf of the Manufacturer. Water quality goals and target removal goals for the water treatment equipment shall be recorded in the Product-Specific Test Plan in the statement of objectives.

10.2 Experimental Objectives

A list of the minimum number of water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 2. The actual water quality parameters selected for testing shall be stipulated by the Manufacturer in the Product-Specific Test Plan and shall include all those necessary to permit verification of the statement of performance objectives. The characterization of feed water is intended to provide sufficient information to enable verification report readers to compare the quality of the feed water used in Verification Testing with the quality of source water at a site where the use of the equipment may be proposed.

10.3 Work Plan

The manufacturer will be responsible for establishing the precoat filtration equipment operating parameters, on the basis of the initial test runs. The filter shall be operated continuously until terminal headloss is attained, at which time it shall be cleaned and precoated in preparation for another run.

Many of the water quality parameters described in this task will be measured on-site by the NSF-qualified Testing Organization (refer to Table 3). Analysis of the remaining water quality parameters will be performed by a state-certified or third party- or EPA-accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field will be described in the Analytical Methods section below and in Table 3. The analytical methods utilized in this study for on-site monitoring of feedwater and filtered water qualities are described in Task 6, Quality Assurance/Quality Control (QA/QC). Where appropriate, the *Standard Methods* reference numbers for water quality parameters are provided for both the field and laboratory analytical procedures. One analytical procedure that is not required but which might prove helpful if excessive clogging of the filters is encountered is the Microscopic Particulate Analysis (MPA) for Filtration Plant Optimization (EPA 910-R-96-001).

10.3.1 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during each period of filtration testing, as noted in this section. Additional sampling and data collection may be performed at the discretion of the Manufacturer. Sample collection frequency and protocol shall be defined by the Manufacturer in the Product-Specific Test Plan.

In the case of water quality samples that will be shipped to the state-certified or third party- or EPA-accredited analytical laboratory for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the state-certified or third party- or EPA-accredited analytical laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory.

10.4 Analytical Schedule

During Verification Testing for precoat filtration treatment equipment, the feedwater (raw water) quality and filtered water quality shall be characterized by measurement of the following water quality parameters:

- temperature (daily)
- pH (desired weekly but optional)
- total alkalinity (desired weekly but optional)
- hardness (desired weekly but optional)
- total organic carbon (desired weekly but optional)
- iron (weekly)
- manganese (weekly if above 0.05 mg/L in feed water)
- algae, number and species (weekly if no bloom; daily if bloom occurs)
- UV_{254} absorbance (desired weekly but optional)
- total coliform bacteria (desired every other day but optional)
- turbidity (continuous for filtered water)
- particle counts (see Task 4)
- dissolved oxygen (daily, but only for "vacuum" precoat filters and not for pressure filters)

Turbidity of filtered water shall be measured and recorded using a continuous, flow-through turbidimeter. Turbidity of feed water (before addition of body feed or any other substance) shall be measured continuously using a flow-through turbidimeter or at intervals of not more than four (4) hours if a bench model turbidimeter is used for grab samples. On a daily basis a bench model turbidimeter shall be used to check the continuous turbidimeter readings.

The above water quality parameters are listed to provide verification report readers with background data on the quality of the feed water being treated and data on the quality of the filtered water. These data are to be collected to enhance the usefulness of the Verification Testing data to a wide range of verification report readers.

10.5 (Optional Task) Turbidity Spiking

If the anticipated turbidity at the selected site does not challenge the system to the limits of its performance objectives, an optional turbidity augmentation procedure may be implemented after the 272-hour period of verification testing has been completed. A procedure for turbidity spiking was published in *Journal AWWA* in December 1993, pp. 39-46 by Logsdon et al. A spiking procedure based on the published technique is described in the following paragraphs. (In this ETV document, when the word "tank" is used, this term includes a storage tank, an above-ground swimming pool of appropriate size, an earthen basin having a plastic liner, or any other device or means of holding large volumes of water.)
To spike turbidity, use of a local turbidity source is recommended. This could consist of sediments taken from the bottom of a river or lake, or natural soil of the type likely to erode into nearby watercourses and cause turbid waters. For testing done in many locations in the United States where row crop agriculture is practiced, topsoil could be used to prepare a suspension for turbidity spiking, because topsoil is a major contributor to turbid runoff as a result of heavy rains in such locations. Topsoil or sediments would be expected to contain some natural organic matter, and as such would enable the FTO to produce a turbidity suspension typical for much of the turbid runoff found in the United States.

The soil or sediments that will be used to prepare a suspension for turbidity spiking should be screened through a three inch screen to remove rocks, for protection of pumps that will be used to mix soil and water.

After screening, soil or sediment should be added in a batch tank having a capacity in the range of 400 to 1000 gallons. Mixing can be accomplished by using a pump with a flow capacity, expressed in gallons per minute, of about 10 percent of the batch tank volume, expressed in gallons. For a 400 gallon batch tank, a 40 gpm pump theoretically could pump one tank volume in 10 minutes. Use of a trash pump or dewatering pump capable of pumping very muddy water or suspensions of water and mud is recommended. The mixture of water and soil or sediment should be recirculated for about six to eight hours. The action of the pump impeller will help to break up soil particles to smaller sizes that do not settle rapidly.

After the turbidity slurry has been mixed as described above and then settled for one hour to allow small gravel, sand, and grit to settle to the bottom of the batch tank, the slurry can be transferred to a very large tank having the capacity in the range of 10,000 to 15,000 gallons. The diluted suspension should be stirred or recirculated using a gasoline-powered portable pump of the kind used for dewatering at project construction sites, or an electric powered pump of equivalent flow capacity. The objective is to mix the water and slurry with a turnover time of about one hour. This mixing should be done for about six to eight hours, followed by two hours of quiescent settling for removal of the larger particles that would settle of their own accord during treatment. After settling, the turbidity suspension can be blended into feed water to make a more turbid feed water, or depending on the size of the treatment equipment being evaluated, and the length of the filter run, the turbidity suspension in the large tank might be used directly as feed water. If the turbidity suspension was to be used directly, more uniform turbidity could be attained by transferring the suspension to a second large tank that could be continuously stirred.

Depending on the number and duration of filter runs for which highly turbid water will be needed, sequential use of two large tanks may be appropriate. In such a situation, one large tank would be

used for stirring and settling the turbidity slurry, while the second large tank would be used as the source of turbid water for spiking or as the source of feed water.

As an alternative to the use of the 10,000 to 15,000 gallon tanks described above, a second tank in the size range of 400 to 1000 gallons could be used. In this case, the suspension that had been mixed in the first 400 to 1000 gallon tank would be settled for two hours in the original tank, and about 80 percent of the contents would be decanted from the first tank to the second tank, leaving the sediments on the bottom undisturbed. The second tank should be stirred to maintain the turbidity-causing particles in suspension. The suspension that has been transferred to the second tank could be fed as a concentrated suspension and thoroughly mixed into the source water to create the turbid feed water. In this approach to turbidity spiking, an in-line mixer should be used to ensure effective mixing of the turbidity suspension and the source water. Sampling of feed water for turbidity analysis should be done only after the spiked turbidity suspension is thoroughly mixed into the feed water. After the turbidity suspension has been transferred to the second tank where the suspension can be used for spiking, preparation of another batch of turbidity suspension could begin again in the first tank.

The size of the tanks and the amount of soil or sediment slurry originally prepared in the highly concentrated form in the first mixing tank (the 400 to 1000 gallon tank described above) may be influenced by the rate of flow of the package treatment equipment being tested, and by the level of turbidity the FTO is trying to attain. Use of treatment equipment with larger flows, and selection of high turbidity goals may result in the need for bigger tanks and pumps and the use of considerably more soil, silt, or sediment. An estimate of the amount of soil could be made by estimating the mass concentration of suspended solids needed to produce a desired turbidity. In making such an estimate, though, the FTO should consider that a substantial portion of the soil might not be broken up into particles so fine that they do not settle out in the recommended settling times. Therefore, soil usage estimates based on suspended solids would understate actual soil requirements.

The turbid water fed in the treatment testing could be characterized by particle counting, in addition to turbidity measurement. In many cases this would require dilution of the turbid samples. A simpler test would be to simply collect a sample of the water and place it in a 1000 mL graduated cylinder, and then record the location of the interface between turbid water and clearer water over a period of three to five hours as the suspension settles. A turbidity suspension that settled very slowly would be representative of turbid water containing fine particulate matter that would be found in many surface waters after heavy runoff.

10.6 Evaluation Criteria

Evaluation of water quality in this task is related to meeting any water quality objectives indicated by the Manufacturer.

- Turbidity removal equals or exceeds goals specified by the Manufacturer; and
- Water quality and removal goals specified by the Manufacturer.

11.0 TASK 3: DOCUMENTATION OF OPERATING CONDITIONS AND TREATMENT EQUIPMENT PERFORMANCE

11.1 Introduction

During each day of Verification Testing, operating conditions shall be documented. This shall include descriptions of treatment processes used and their operating conditions. In addition, the performance of the water treatment equipment shall be documented, including filtration rate, rate of filter head loss gain, length of filter run and terminal head loss; grade and brand, and amount (kg/m^2) of diatomaceous earth or perlite used for precoat; grade and brand, and concentration (mg/L) of diatomaceous earth or perlite used for body feed. Operating conditions are likely to be evaluated in great detail by state reviewers and are an important aspect related to approval of equipment by states.

11.2 Objectives

The objective of this task is to accurately and fully document the operating conditions that applied during treatment, and the performance of the equipment. This task is intended to result in data that describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

11.3 Work Plan

A complete description of each process shall be given. Data on the filter shall be provided and shall include the following:

- whether the equipment is a pressure filter or a vacuum filter
- if flat filter elements are used is septum made of stainless steel mesh, synthetic fiber mesh, or other?
- if cylindrical filter elements are used, are they made of porous ceramic, sintered material, flexible woven wire, synthetic mesh, or other?
- description of the method employed for removal of spent diatomaceous earth or perlite at the end of a run and cleaning of filter elements
- description of the precoating technique, and statement of the amount of precoat used (kg/m^2)
- brand and grade of diatomaceous earth or perlite used for precoating and for body feed - if information on particle size distribution and porosity is available from the filter aid manufacturer, this information shall be provided
- any special preparation of the diatomaceous earth or perlite, such as coating with aluminum hydroxide precipitates or polymers - modification of the filtration properties of diatomaceous earth or perlite by coating the filter aids with aluminum hydroxide precipitates or with polymers is not commonly practiced but if done, this shall be completely and carefully documented

The manufacturers of filter aid materials and the manufacturers of precoat filtration equipment are very likely to be different entities. The organization (manufacturer or qualified testing organization) which selects the brands and grades of filter aid materials to be used in testing of precoat filtration equipment shall also obtain descriptive information from the filter aid manufacturer about each filter aid used in the testing program.

In addition, system reliability features including redundancy of components, shall be described. Spatial requirements for the equipment (footprint) shall be stated.

During each day of Verification Testing, treatment equipment operating parameters for precoat filtration shall be monitored and recorded on a routine basis. This shall include rate of flow, filtration rate, and maximum head loss. When pressure filtration equipment is used, the water pressure on both the influent side and the discharge side of the filtration equipment shall be recorded. Data on filter precoating procedures and body feed shall be collected. Electrical energy consumed by the treatment equipment shall be measured, or as an alternative, the aggregate horsepower of all motors supplied with the equipment could be used to develop an estimate of the maximum power consumption during operation. Performance shall be evaluated to develop data on diatomaceous earth or perlite consumed (for both precoating and body feed) and on energy needed for operation of the process train being tested.

A daily log shall be kept which events in the watershed are noted if they could influence source water quality. This includes such things as major storm systems, rainfall, snowmelt, temperature, cloud cover, upstream construction activities that disturb soil, and intermittent operation of hydroelectric generating facilities.

Performance of precoat filtration for removal of turbidity and microorganisms can be strongly influenced by the particle size distribution of the diatomaceous earth or perlite filter aid and by the pore sizes of the filter aid cake through which the water is filtered. Therefore the grade and brand of filter aid material used when turbidity or microorganism data are gathered shall be identified. The types (grade and brand) of filter aid shall not be changed during a filter run, but only after completion of a run, when the filter must be cleaned before precoating. If different grades or brands of filter aid are used during Verification Testing, the water quality data collected in conjunction with the use of each filter aid shall be analyzed and presented separately. Data shall be developed on the volume of spent filter aid slurry produced per 1000 volumes of water filtered (e.g., gallons of slurry per 1000 gallons of water filtered or cubic meters of slurry per 1000 cubic meters of water filtered).

11.4 Schedule

Table 4 presents the schedule for observing and recording precoat filtration equipment operating and performance data.

11.5 Evaluation Criteria

Where applicable, the data developed from this task will be compared to statements of performance objectives.

If no relevant statement of performance objectives exists, results of operating and performance data will be tabulated for inclusion in the Verification Report.

12.0 TASK 4: MICROBIOLOGICAL CONTAMINANT REMOVAL

12.1 Introduction

Removal of microbiological contaminants is a primary purpose of filtration of surface waters. Consequently, the effectiveness of precoat filtration treatment processes for microbial removal will be evaluated in this task. Assessment of treatment efficacy will be made on the basis of particle counting, removal of one or more microorganisms, removal of polymeric microspheres, or a combination thereof, depending on the manufacturers statement of treatment capability with regard to microorganism removal.

The precoat filtration process removes microorganisms in the size range of *Giardia* and *Cryptosporidium* from water by physically straining out the particles, trapping them in the filter cake which consists of diatomaceous earth or perlite. Walton (1988) presented photographic evidence showing that *Giardia* cysts are strained out and trapped in the fine pores of the filter cake. AWWA Manual M30 (1995) states, "The basic function performed by all water filters is to remove particulate matter from the water. Precoat filters accomplish this by physically straining the solids out of the water." Because the particle removal mechanism is primarily by straining out particles from water on the basis of the sizes of the particles and of the pores in the filter cake, the applicability of surrogate particles depends on their size and shape, rather than on their biological nature. Thus appropriately sized microspheres could be suitable surrogates for protozoan cysts and oocysts. Schuler and Ghosh (1990) evaluated precoat filtration for protozoan cyst and oocyst removal and obtained greater than 99.9% removal of *Cryptosporidium* using diatomaceous earth with no chemical conditioning. In other tests they conditioned diatomaceous earth with alum or polymer before using it as a precoat filter aid or body feed filter aid and attained equal or better results.

Studies of diatomaceous earth filtration have shown that precipitation of aluminum hydroxide coating onto diatomaceous earth used in precoating and body feed can enhance removal of particles too small to be effectively trapped in the diatomaceous earth filter cake pores (Lange et al, 1986). Use of cationic polymer to coat diatomaceous earth has also been demonstrated to have a beneficial effect on removal of microorganisms such as viruses that would be removed less effectively by plain (uncoated) diatomaceous earth (Brown et al, 1974). If removal of bacteria and viruses is an objective of the Verification Testing for precoat filtration, use of alum coating or cationic polymer may be needed in order to attain the most effective results. If filter aid properties are to be modified by use of alum or polymer, the procedures used for such modification shall be clearly described in the Product-Specific Test Plan.

Removal of turbidity by precoat filtration is not synonymous with removal of protozoan organisms because turbidity-causing particles can be much smaller than protozoa, and precoat filters can remove protozoan-sized particles while passing particles in the size range of bacteria, or the micron-sized and sub-micron-sized particles that cause turbidity. Therefore turbidity removal is not a surrogate for protozoan removal in precoat filtration (Logsdon et al., 1981).

Use of electronic particle counting to assess protozoan removal would be appropriate only for feed waters containing large numbers of particles in the size range of *Cryptosporidium*. For *Cryptosporidium* oocyst removal, assessment of particle removal in the size range of 3 to 7 μm would be appropriate. If sufficient concentrations of appropriately sized particles are not present in the feed water, use of electronic particle counting may not be capable of demonstrating adequately high log removals.

Research has shown (Lange et al., 1986) that total coliform removal varies with the grade (particle size) of diatomaceous earth used. Therefore, microbiological results must be related to the grade and brand of diatomaceous earth or perlite used in the Verification Testing.

Microbiological challenge testing for removal of bacteria is needed only if the Manufacturer's statement of performance objectives indicates that bacteria can be removed by the precoat filtration equipment. Microbiological challenge testing for removal of viruses is needed only if the Manufacturer's statement of performance objectives indicates that viruses can be removed by the precoat filtration equipment. Challenge tests conducted with bacteria or viruses may not be relevant for protozoan oocyst or cyst removal or indicative of the results to be expected for protozoan oocysts or cysts in precoat filtration equipment testing.

12.2 Experimental Objectives

The objective of this task is to evaluate removal of particles and microbiological contaminants during Verification Testing by measuring removal of microorganisms naturally present in the feed water; by measuring the removal of microorganisms seeded into the feed water; by assessing removal of polystyrene fluorescent microspheres; by electronic particle counting; or with a combination of these techniques. Seeded microorganisms may be bacteria or coliphage. Both *Giardia* and *Cryptosporidium* are pathogens of public health concern. *Cryptosporidium* is the smaller organism, so testing with a surrogate for *Cryptosporidium* would indicate the results that would be expected for *Giardia* removal, which would be removed as well as or better than *Cryptosporidium*. *Cryptosporidium* oocyst removal of up to 6-log has been reported (Ongerth and Hutton, 1997), with results being somewhat dependent on the grade (permeability) of the diatomaceous earth used.

12.3 Work Plan

The portions of Task 4 (required portions consisting of electronic particle counting and microsphere challenge testing, plus optional portions, if any) shall be carried out during the Verification Testing runs being conducted in Task 1. A minimum of three test runs shall be conducted during each period of Verification Testing to provide verifiable microorganism or surrogate particle removal data that can be analyzed statistically.

12.3.1 Electronic Particle Counting

Use of electronic particle counting is a required portion of Task 4, both for providing general information on particle removal and specific information on removal of particles such as *Cryptosporidium*. When an electronic particle counter is used for a general evaluation of particle removal, particle counts in feed water before any seeding and before any addition of body feed diatomaceous earth or perlite) and particle counts in filtered water shall be measured.

For evaluation of *Cryptosporidium* oocyst removal, particles in the size range of 3 to 7 μm shall be counted. If particles are not present in sufficient densities (concentrations) to permit calculation of log removals of protozoan-sized particles consistent with the Manufacturer's statement of performance capability, then particle counting for log removal should be done during microsphere challenge events.

12.3.2 Microspheres

For microspheres intended to serve as surrogates for *Cryptosporidium* oocysts in Verification Testing, the nominal diameter shall be 3 to 5 μm, based on commercially available sizes. This mix of sizes can be attained by purchasing 3 μm and 5 μm microspheres and seeding a 50/50 (by volume) blend of the two suspensions. If blended on an equal volume basis this mixture would have a higher proportion of the smaller microspheres. Microspheres have been used as surrogates for *Giardia* cysts in precoat filtration research. This was considered feasible because the particle removal mechanism for cyst-sized particles was straining (Logsdon et al., 1981).

Evaluation of microsphere removal shall be conducted by determining the density (concentration) of microspheres in the precoat filtration equipment feed water and in the filtered water. Counting of microspheres in water may be done using electronic particle counting, if the microspheres can be detected in both the feed water and the filtered water. If the density of microspheres in filtered water is too low to be reliably measured by electronic particle counting, then a microscopic enumeration technique shall be used. In either case, microspheres must be seeded into the feed water, mixed adequately, and sampled before any body feed filter aid is added to the feed water. Use of a static or in-line mixer that results in head loss of about 0.3 to 0.5 feet of water is recommended.

If electronic particle counting is not feasible, enumeration of microspheres in feed water and filtered water by optical microscopy shall be required. For testing involving microscopic enumeration of microspheres, fluorescent microspheres shall be used, and an optical microscope equipped with ultraviolet illumination shall be used to enumerate the microspheres. For microspheres intended to serve as surrogates for *Cryptosporidium* oocysts, the nominal diameter shall be 3 μm to 5 μm.

During filtration tests in which polymeric microspheres are seeded into the feed water, the microspheres shall be suspended in a solution of 0.01% Tween 20. The microsphere suspension shall be gently stirred during the time when microspheres are being injected into the feed water. Before each run with seeded microspheres, the holding vessel shall be washed with hot water and laboratory glassware detergent and thoroughly rinsed with tap water or filtered water. The number of microspheres used shall be sufficient to permit calculation of log removals that exceed the removal capability as set forth in the Manufacturer's statement of performance objectives. Recovery of microspheres in filtered water provides data for use in calculating definite removal percentages, in contrast to the practice of reporting removals that exceed a specified value based on the detection limit, which would have to be done when no microspheres are detected in filtered water.

Two techniques for analysis of water samples containing fluorescent microspheres may be used. One is the method used by Abbaszadegan *et al*. (1997) for enumeration of *Giardia* cysts and *Cryptosporidium* oocysts, and the other is the method of Li *et al*. (1997) which they used for enumeration of microspheres.

If the techniques for microsphere sampling and enumeration are based on the research work of Li *et al.* (1997) which was carried out at the U.S. EPA's research laboratory in Cincinnati, the procedures below shall be followed.

Samples of feed water seeded with microspheres and filtered water shall be filtered through 1 μm pore size, 293 mm diameter polycarbonate membranes. A stainless steel filter manifold shall be used to support the polycarbonate membrane. Volume of water filtered, and the times of initiation and completion of filtration shall be noted. The filter shall be removed from the manifold, placed in a storage container, and refrigerated until shipment to the EPA-accredited analytical laboratory. At the analytical laboratory the microspheres shall be removed from the filter with a laboratory squeegee and by washing with about 200 mL of 0.01% Tween 20. The liquid and particulate matter removed from the membrane shall be concentrated to a volume of between 1 and 10 mL by means of centrifugation for 10 minutes at 1200 x gravity. The volume of the concentrated suspension shall be recorded. Microspheres shall be enumerated using a hemacytometer under a UV microscope at 400 magnification. A minimum of three hemacytometer counts shall be performed for each sample. The volume of suspension examined in the hemacytometer shall be recorded and used to determine the fraction of the original water sample which was ultimately examined under the microscope. *Standard Methods* states that hemacytometer chambers come with detailed manufacturer's instructions concerning calculations and proper usage.

Standard Methods contains the precaution that a disadvantage of hemacytometers is that the sample must have a very high density of objects being counted in order to yield statistically reliable data. Some exploratory tests may be needed to identify appropriate volumes of treated water to filter through the polycarbonate membrane or appropriate densities (concentrations) of microspheres in the seeded feed water, so that reliable statistics can be attained in filtered water analysis. The total number of microspheres counted in the hemacytometer should be between 30 and 300 to obtain good statistical results without counting overwhelming numbers of microspheres.

If the entire flow stream produced by the precoat filtration equipment can not be filtered through the 293 mm membrane filter for sampling, a measured portion of the total filtered water flow can be sampled as it is produced, or the entire flow of filtered water from a seeding test can be stored in clean vessel and later filtered through the 293 mm membrane filter at a rate of flow suitable for the membrane filter. If an instantaneous slug dose of microspheres is applied and the entire volume of filtered water is saved in a storage vessel for subsequent membrane filtration as the sampling procedure, at least 20 times the volume of the precoat filtration pressure vessel or open filtration tank shall be filtered through the precoat filtration equipment and saved for sampling and analysis. (If this volume is impractically large, then seeding of microspheres on a continuous basis is the only acceptable seeding technique.)

12.3.3 Challenge Tests with Microorganisms

Microbiological testing, if done, shall be performed by seeding one or more of the kinds of organisms listed in Table 5 into the feed water or by testing for ambient organisms in the feed water, and by analyzing for the organisms in question in the feed water and in the filtered water. If challenge testing is done with seeded bacteria or coliphage, the manufacturer may find it helpful to evaluate the use of filter aids conditioned with metal coagulant or polymer.

The bacteria listed in Table 5 are considered representative of the sizes of bacteria that would be encountered in natural waters.

MS2 bacterial virus was identified for use as the model virus for the optional virus challenge studies. MS2 virus is the virus of choice for challenge studies because it is similar in size (0.025 μm), shape (icosahedron) and nucleic acid (RNA) to polio virus and hepatitis. This bacterial virus is the suggested organism to use in the SWTR Guidance Manual when conducting studies of microbial removal (USEPA, 1989).

If sufficient numbers of bacteria are naturally present in the feed water so that 3-log removal can be calculated without seeding bacteria, treatment equipment shall be operated as usual in Verification Testing runs, and sampling shall be done as stipulated in the Analytical Schedule if data on bacteria removal by precoat filtration are obtained during Verification Testing.

If testing is done with seeded organisms, an initial control test lasting 2 to 3 hours shall be made in which the organisms are seeded but the filter is operated with no precoat and no body feed filter aid. This test shall be done to evaluate organism losses through the filter equipment. When microorganisms are seeded, they shall be injected into the feed water at the same location that is used for seeding microspheres into the feed water.

For testing with seeded microorganisms, the microorganisms shall be used in densities sufficient to permit calculation of at least 3-log removal, and seeding of microorganisms shall begin at start-up of the treatment equipment. The organism feed suspension will be prepared by diluting the organisms to be seeded into dilution water that is distilled or deionized and disinfectant free. The feed reservoir for the organism suspension shall be made of biologically inert material (i.e., not toxic to the organisms in the suspension) and cleaned with hot water and laboratory glassware detergent followed by thorough rinsing before each test run in which microorganisms are seeded. The reservoir will be mixed continuously but gently, as with a magnetic stirring bar, throughout the experiment and kept packed in ice in a cooler. The seed suspension will be fed into the feedwater using an adjustable rate chemical feed pump. Mixing of this suspension with the feedwater will be accomplished using an in-line static mixer as described previously. Sample collection for seeded organisms should be made at the same location that is used for collection of microsphere samples.

If virus (coliphage) challenges are undertaken, water samples of at least 100 mL volume will be collected. Virus samples shall be shipped to an EPA-accredited laboratory for analysis.

12.4 Analytical Schedule

Analysis of feed water samples by electronic particle counters may be done on a batch or a continuous basis. If batch measurements are made, they shall be made for at least 8 hours each working day during Verification Testing with samples collected and analyzed at least once each hour. Filtered water analysis shall be done using flow-through particle counters, equipped with recording capability so data can be collected on a 24-hour-per-day basis during Verification Testing.

When microspheres are seeded for a period of hours on a continuous basis, microsphere samples shall be collected from the plant influent (feed water after seeding) and the filter effluent. Samples shall not be collected until the treatment plant has been in operation for a total of 3 theoretical detention times as measured through the filter vessel. For microsphere sampling purposes, the time of operation when three filtration vessel detention times have elapsed shall be considered time zero. Microsphere samples shall be collected at time zero and at 0.5 and 1 hours past time zero. Microsphere samples shall also be collected during the time period that is estimated to occur between

85% and 95% of the total run length, based on prior filter run performance. Seeding of microspheres, if not done continuously from the beginning of the run to the end of the run, shall be done during the first 1.5 hours of operation and shall again be started 1 hour before the time that is estimated to represent 85% of the total run length. The time of sampling shall be recorded so turbidity measurements can be determined at the time of sampling. Volumes of feed water and filtered water to be filtered should be large enough that 30 to 300 microspheres are detected in each seeded feed water sample. Ideally for statistical purposes 30 to 300 microspheres should be detected in each filtered water sample also. If the filtration process is highly efficient for removal of the microspheres, detection of such large numbers in samples of filtered water would not be possible. In such a case, detection of at least 5 microspheres is desirable. If removal is extremely high, detecting 5 or more microspheres in filtered water may not be possible but probably would be indicative of very high log removals of microspheres.

When microspheres are seeded on a slug dose basis, the number of microspheres in the concentrated suspension shall be based on an analysis of the concentrated suspension before it was dosed. The entire production of filtered water shall be collected for sampling, from the instant of dosing until a volume of filtered water equal to 20 volumes of the filter vessel has been collected. For example, if the filter vessel volume is 100 liters, a 2000-liter sample of filtered water shall be collected and then filtered through a membrane filter as described above in the procedure of Li *et al.*
If microbiological challenge testing is undertaken, microbiological samples shall be collected from feed water and filtered water on the same schedule stipulated for microsphere samples.

The Testing Organization shall then submit collected water samples to an EPA-accredited analytical laboratory for microbial testing.

12.5 Evaluation Criteria

Performance evaluation shall be conducted in a number of ways, depending on the types of data collected during testing.

Performance of precoat filtration equipment shall be evaluated in the context of the Manufacturer's statement of performance objectives. Turbidity results will be analyzed to determine the percentage of turbidity data in the range of 0.50 NTU or lower, the percentage between 0.51 NTU and 1.0 NTU, and the percentage that exceeded 1.0 NTU. The time intervals used for determining filtered water turbidity values shall be the same for all data analyzed, and because continuous turbidimeters are to be used to collect turbidity data, the intervals shall be between 15 and 60 minutes.

Electronic particle count data shall be evaluated by calculating the change in total particle count from feed water to filtered water, expressing the change as log reduction. The aggregate of particle counting data obtained during each verification testing period shall be analyzed to determine the median log removal and 95th percentile log removal during that verification testing period. Because of possible complications in conducting electronic particle counts on feed water, 1 to 4 hour time intervals shall be used for analysis of particle counting data for log reduction of particles.

Data on the density of microspheres in feed water and filtered water shall be analyzed to determine the median log removal and 95th percentile log removal during that verification testing period.

Data on the density of microorganisms in feed water and filtered water shall be analyzed to determine the median log removal and 95th percentile log removal during that verification testing period.

Particle counting data taken throughout the filter runs shall be used to determine whether particle removal performance improves, remains about the same, or declines throughout the course of a precoat filtration filter run, as the filter cake thickness increases and head loss increases.

13.0 TASK 5: DATA MANAGEMENT

13.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software or manual recording methods, or both, for recording operational parameters for the precoat filtration equipment on a daily basis.

13.2 Experimental Objectives

One objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Testing Organization provides sufficient and reliable operational data for verification purposes. A second objective is to develop a statistical analysis of the data, as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies."

13.3 Work Plan

13.3.1 Data Management

The following protocol has been developed for data handling and data verification by the Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels will be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data will be manipulated into a convenient framework to allow analysis of equipment operation. Backup of the computer databases to diskette should be performed on a monthly basis at a minimum.

In the case when a SCADA system is not available, field testing operators will record data and calculations by hand in laboratory notebooks. (Daily measurements will be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook will provide carbon copies of each page. The original notebooks will be stored on-site; the carbon copy sheets will be forwarded to the project engineer of the Testing Organization at least once per week. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include a description of the precoat filtration equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project will be set up in the form of custom-designed spreadsheets. The spreadsheets will be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheet. Data entry will be conducted on-site by the designated field testing operators. All recorded calculations will also be checked at this time. Following data entry, the spreadsheet will be printed out and the print-out will be checked against the handwritten data sheet. Any corrections will be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet will be printed out. Each step of the verification process will be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each filtration test run) will be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA-accredited analytical laboratories, the data will be tracked by use of the same system of run numbers. Data from the outside laboratories will be received and reviewed by the field testing operator. These data will be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

If different grades or brands of filter aid are used during Verification Testing, the water quality data collected in conjunction with the use of each filter aid shall be analyzed and presented separately. Complete data shall also be provided on the use of metal coagulant or cationic polymer to condition the filter aid before its usage in water filtration, if this has been done in any tests.

13.3.2 Statistical Analysis

Water quality data developed from grab samples collected during filter runs according to the Analytical Schedule in Task 4 of this Test Plan shall be analyzed for statistical uncertainty. The Testing Organization shall calculate 95% confidence intervals for grab sample data obtained during Verification Testing as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies." Statistical analysis could be carried out for a large variety of testing conditions. Two conditions that are specifically required to be analyzed statistically are:

- All grab sample data for each Verification Testing run; and
- All grab sample data for every Verification Testing run operated at the same filtration rate and having the same quantity and grade of precoat filter aid and the same concentration and grade of precoat body feed.

The statistics developed will be helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals. Information on the differences in water quality for filter runs having different grades or quantities of filter aid or different concentrations of body feed or different amounts of precoat filter aid would be useful in evaluating appropriate operating procedures for filter runs.

14.0 TASK 6: QA/QC

14.1 Introduction

Quality assurance and quality control of the operation of the precoat filtration equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or *Standard Methods*. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 Work Plan

Equipment flow rates and associated signals should be documented and recorded on a routine basis. A routine daily walk-through during testing will be established to verify that each piece of equipment or instrumentation is operating properly. Particular care will be taken to confirm that filter aid is being fed at the defined flow rate into a flow stream that is operating at the expected flow rate. In-line monitoring equipment such as flow meters, etc. will be checked to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

14.4 Daily QA/QC Verifications:

- Body feed flow rates (verified volumetrically over a specific time period)
- In-line turbidimeter flow rates (verified volumetrically over a specific time period)
- In-line turbidimeter readings checked against a properly calibrated bench model
- Batch and in-line particle counter flow rates (checked volumetrically over a specific time period).

14.5 QA/QC Verifications Performed Every Two Weeks:

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

14.6 QA/QC Verifications For Each Testing Period:

- In-line turbidimeters (clean out reservoirs and recalibrate)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)
- Particle counters (perform microsphere calibration verification)
- If challenge tests are going to be conducted with bacteria or coliphage, a control test shall be done at the beginning of the test period to evaluate the recovery of the test organism or organisms used, when low-turbidity water is passed through the treatment equipment at its intended rate of flow but no precoat filter aid and no body feed filter aid are to be used.

14.7 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of raw water and filtered water quality are described in the section below. In-line equipment is recommended for its ease of operation and because it limits the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. In-line equipment is recommended for measurement of turbidity and for particle counting for feed water and is required for measurement of turbidity and for particle counting for filtered water.

14.7.1 pH

Analysis for pH shall be performed according to *Standard Methods* 4500-H^+ or EPA Method 150.1/150.2. A three-point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

14.7.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Methods* 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1°C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1°C to +51°C, subdivided in 0.1° increments, would be appropriate for this work.)

14.7.3 Dissolved Oxygen

Analysis for dissolved oxygen shall be performed according to *Standard Method* 4500-O using an iodometric method or the membrane electrode method. The techniques described for sample collection must be followed very carefully to avoid causing changes in dissolved oxygen during the sampling event. Sampling for dissolved oxygen does not need to be coordinated with sampling for other water quality parameters, so dissolved oxygen samples should be taken at times when immediate analysis is going to be possible. This will eliminate problems that may be associated with holding samples for a period of time before the determination is made.

14.7.4 Turbidity Analysis

Turbidity analyses shall be performed according to *Standard Methods* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters shall be used for measurement of turbidity in the filtrate waters, and either an in-line or bench-top turbidimeter may be used for measurement of the feedwater.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back

to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

14.7.4.1 Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of equipment operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples that cause the vial to fog preventing accurate readings, allow the vial to warm up by submersing partially into a warm water bath for approximately 30 seconds.

14.7.4.2 In-line Turbidimeters. In-line turbidimeters are required for filtered water monitoring during verification testing and must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow rate should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

14.7.5 Particle Counting

In-line particle counters shall be employed for measurement of particle concentrations in filtrate waters. However, either a bench-top or an in-line particle counter may be used to measure particle concentrations in the feedwater, concentrate (where applicable) and pretreated waters (where applicable). Laser light scattering or light blocking instruments are recommended for particle counting during verification testing. However, other types of counters such as Coulter counters or Elzone counters may be considered for use if they can

be configured to provide continuous, in-line monitoring for the filtrate product water stream. The following discussion of operation and maintenance applies primarily for use of laser light blocking instruments.

The following particle size ranges (as recommended by the AWWARF Task Force) shall be monitored by both in-line and bench-top analytical instruments during the verification testing:

- 2-3 μm
- 3-5 μm
- 5-7 μm
- 7-10 μm
- 10-15 μm
- > 15 μm

The Field Testing Organization shall be required to document any problems experienced with the monitoring particle counting instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

Use of particle counting to characterize feedwater and filtered water quality is required as one surrogate method for evaluation of microbiological contaminant removal.

14.7.5.1 Bench-top Particle Counters. All particle counting shall be performed on-site. The particle sensor selected must be capable of measuring particles as small as 2 μm. There should be less than a ten percent coincidence error for any one measurement.

Calibration. Calibration of the particle counter is generally performed by the instrument manufacturer. The calibration data will be provided by the manufacturer for entry into the software calibration program. Once the data has been entered it should be verified using calibrated commercially-available particle standards or methods. This calibration should be verified at the beginning of each Verification Testing period.

Maintenance. The need for routine cleaning of the sensor cell is typically indicated by: 1) illumination of the sensor's "cell" or "laser" lamps, 2) an increase in sampling time from measurement to measurement, or 3) an increase in particle counts from measurement to measurement. During the ETV testing, the sensor's "cell" and "laser" lamps and the sampling time will be checked periodically. The number of particles in the "particle-free water" will also be monitored daily.

Particle-Free Water System. "Particle-free water" (PFW) will be used for final glassware rinsing, dilution water, and blank water. This water will consist of de-ionized (DI) water that has passed through a 0.22-μm cartridge filtration system. This water is expected to contain fewer than 10 total particles per mL, as quantified by the on-site particle counter.

Glassware Preparation. All glassware used for particle counting samples shall consist of beakers designed specifically for the instrument being used. Glassware will be cleaned after every use by hand washing using hot water and laboratory glassware detergent solution followed by a triple PFW rinse. Sample beakers will then be stored inverted. Dedicated beakers will be used at all times for unfiltered water (feed water before addition of body feed), diluted unfiltered water, filtered water, and PFW. When several samples are collected

from various equipment sampling points during one day, the appropriate beakers will be hand-washed as described above, and then rinsed three times with sample prior to collection. Other materials in contact with the samples, including volumetric pipettes, volumetric flasks, and other glassware used for dilution, will also be triple-rinsed with both PFW and sample between each measurement.

Sample Collection. Beakers should be rinsed with the sample at least three times prior to sample collection for particle counting. Sample taps should be opened slowly prior to sampling. Sudden changes in the velocity of flow through the sampling taps should be avoided immediately prior to sample collection to avoid scouring of particles from interior surfaces. A slow, steady flow rate from the sample tap will be established and maintained for at least one minute prior to sample collection. The sample will be collected by allowing the sample water to flow down the side of the flask or beaker; thereby minimizing entrainment of air bubbles.

Dilution. The number of particles in the raw waters is likely to exceed the coincidence limit of the sensor. If so, these samples will be diluted prior to analysis. In all cases, PFW will be used as dilution water. When necessary, dilutions will be performed as follows:

- Dilution water will be dispensed directly into a 500-mL volumetric flask;
- A volumetric pipette (i.e. 10-mL for a 50:1 dilution) will be used to collect an aliquot of the sample to be diluted (stock);
- The appropriate volume of the stock will be slowly added to the volumetric flask containing the dilution water;
- The volumetric flask will be slowly filled to the full-volume etch with dilution water;
- The volumetric flask will be inverted gently and then its contents will be poured slowly into the appropriate 500-mL flask for analysis.

During each of the above steps, care will be taken to avoid entrainment of air bubbles; thus, samples and dilution water will flow slowly down the side of containers to which they are added. Excessive flow rates through pipette tips, which can cause particle break-up, will be avoided by use of wide-mouth pipettes. Sample water will be drawn into and out of pipettes slowly to further minimize particle break-up.

$$Sample\ Particle\ Concentration = \frac{\{MP - (1 - X) \times PF\}}{X}$$

Actual particle counts in a size range for diluted samples will be calculated based on the following formula:

where MP is the measured particle concentration (particles per mL) in the diluted sample, PF is the measured particle concentration (particles per mL) in the particle-free water, and X represents the dilution factor. For a 25:1 dilution, the dilution factor would be 1/25, or 0.04. The expression for the dilution factor is provided by the following equation:

$$Dilution\ Factor = X = \frac{Volume\ Sample}{Addition\ of\ Volume\ Sample + Volume\ Dilution\ Water}$$

Particle Counting Sample Analysis. To collect samples for particle counting, at least 200 mL of each water sample to be counted (diluted or not) should be collected in the appropriate beaker. The beaker will be placed into the pressure cell and counting will take place in the "auto" mode of the instrument. Four counts will be made of each sample. The first count will serve to rinse the instrument with the sample; data from this count are discarded. Data from the subsequent three counts will be averaged, and the average value will be reported as the count for that sample.

14.7.5.2 In-line Particle Counters. Any in-line particle sensors selected for use must have capabilities for measurement of particles as small as 2 μm and have a coincidence error of less than ten percent. The particle counter manufacturer shall provide data and methods that the in-line particle sensors meet these criteria or an independent third party shall verify the in-line particle sensor meets the above criteria. The particle counter manufacturer shall provide the methods for demonstration of coincidence error.

The sensors of the in-line units must also be provided with a recent (two months before the start of testing) manufacturer calibration. The calibration shall be verified by measurement of the individual and cocktail suspensions of the monospheres as described for the batch counter; however, in this case the samples must be fed in-line to the counters.
No dilution of the filtered water samples will be conducted. The data acquired from the counters will be electronically transferred to the data acquisition system. If it is known that a particular sensor will not be used for a period of several days or more, refer to the manufacturer recommendations for an appropriate storage protocol.

14.8 Chemical and Biological Samples Shipped Off-Site for Analyses

14.8.1 Organic Parameters: Total Organic Carbon and UV_{254} Absorbance

Samples for analysis of TOC and UV_{254} absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held, and shipped in accordance with *Standard Method* 5010B. Storage time before analysis shall be minimized, according to *Standard Methods*.

14.8.2 Microbial Parameters: Viruses, Bacteria, and Algae

Samples for analysis of Total Coliforms (TC) and Heterotrophic Plate Counts (HPC) shall be collected in bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped with an internal cooler temperature of approximately 4°C to the analytical laboratory. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited analytical laboratory within the time specified for the relevant analytical method. The laboratory shall keep the samples at approximately 4°C until initiation of analysis. TC densities will be reported as most probable number per 100 mL (MPN/100 mL) or as total coliform densities per 100 mL. HPC densities will be reported as colony forming units per milliliter (cfu/mL).

Algae samples shall be preserved with Lugol's solution after collection, stored and shipped in a cooler at a temperature of approximately 4°C, and held at that temperature range until counted.

14.8.3 Inorganic Samples

Inorganic chemical samples, including alkalinity, hardness, iron, and manganese, shall be collected, preserved, shipped, and held in accordance with *Standard Method* 3010B, paying particular attention to the sources of contamination as outlined in *Standard Methods* 3010C. The samples shall be refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C during shipment. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

14.8.4 Microspheres

The membrane filters used for obtaining microsphere samples shall be refrigerated at approximately 4°C immediately upon collection. Such samples shall be shipped in a cooler and maintained at a temperature of approximately 4°C during shipment and in the analytical laboratory, until they are analyzed. This is done to minimize microbiological growth on the membranes.

Recovery of microspheres from suspensions held in glassware shall be evaluated by preparing a suspension of microspheres in which the number of microspheres used to make the suspension is estimated, based on either the weight of dry microspheres or the volume of microspheres in liquid suspension as provided by the supplier. After the suspension is prepared and mixed until it is homogeneous, five aliquots shall be taken and counted in the hemacytometer. After the microsphere density (concentration) has been calculated, aliquots of the suspension shall be diluted and filtered through polycarbonate membrane filters having 1 μm pore size. The elution and concentration steps described in Task 4 shall be followed, and the microspheres shall be counted in a hemacytometer. This shall be done five times, so that statistics can be developed on the recovery of microspheres in the sampling procedure.

As a check on possible interference from fluorescing organisms in the feed water, during each Verification Testing run in which fluorescent microspheres are used, a sample of feed water with no seeded microspheres shall be filtered through a polycarbonate membrane, and the particulate matter on the membrane shall be concentrated using the procedures for microsphere analysis, and the concentrate shall be examined in a hemacytometer by microscope, with UV illumination. If no objects of the size and shape of the microspheres are seen to fluoresce, displaying the same color as the microspheres, then fluorescent objects of the proper color seen in samples with seeded microspheres can be considered to be microspheres.

Microspheres may adhere to surfaces of tanks, vessels, and glassware. All glassware, holding tanks, and membrane filter manifolds must be cleaned between seeding events or sampling events.

15.0 OPERATION AND MAINTENANCE

The Field Testing Organization shall obtain the Manufacturer-supplied O&M manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for O&M Manuals for equipment employing precoat filtration.

15.1 Maintenance

The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- valves
- filter aid feeders
- mixers
- motors
- quick-opening pressure filter vessels
- instruments, such as turbidimeters
- water meters, if provided

The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- tanks and basins
- piping used to convey filter aid slurries
- filter vessels

15.2 Operation

The manufacturer should provide readily understood recommendations for procedures related to proper operation of the equipment. Among the operating aspects that should be discussed are:

- Filter aid feeders:
- calibration check
- settings and adjustments -- how they should be made
- make-up of body feed slurry (for wet feed systems)

Mixers:

- purpose
- appropriate mixing intensity for maintaining filter aid slurry in suspension

Body feed system:

- importance of maintaining proper body feed at all times

Filtration:

- control of filtration rate
- observation and measurement of head loss during filter run
- filtered water recirculation through filter vessel during times of low demand

Filter precoating:

- Preparation of filter aid precoat slurry
- Recycle of slurry through filter
- Completion of precoating

Filter cleaning:

- end of filter run
- technique for removal of spent filter aid from filter septa or leaves (sluicing, flow reversal, or draining, drying, and vibrating most commonly used)
- conclusion of filter washing
- provision for visual inspection of clean septum provided?
- manual cleaning of septa on periodic (e.g. yearly) basis

Monitoring and observing operation:

- filter vessel inlet pressure
- filter vessel outlet pressure
- raw water turbidity
- filtered water turbidity
- rate of flow
- what to do if turbidity breakthrough occurs

Filter aid selection and handling:

- information on safety aspects of handling of dry filter media
- techniques for determining proper filter aid grade and dosage

Strongly recommend that Manufacturer include a copy of AWWA Manual M30, "Precoat Filtration" with each precoat filtration system, as an AWWA committee of experts has prepared an excellent manual that would be very helpful to plant operators.

The manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- loss of raw water (feed water) flow to plant during a filter run
- poor raw water quality (raw water quality falls outside the performance range of the equipment)
- can't control rate of flow of water through equipment
- no body feed
- mixer will not operate
- filter can't be cleaned
- precoat recycle pump failure
- excessively high head loss through filter septa after spent filter aid cake removed and septa cleaned
- precoat filter aid cake not building up on filter septa during precoating
- uneven build-up of filter aid precoat cake on septa, indicated by lumpy precoat or bare spots on septa, after precoating completed
- no reading on turbidimeter
- automatic operation (if provided) not functioning
- filtered water turbidity too high
- filter head loss builds up excessively rapidly
- no head loss readings

- valve stuck or won't operate
- piping to convey filter aid becomes clogged
- no electric power

It is also recommended that the Manufacturer add a toll free number to the O&M manual for technical assistance on operation and maintenance of the equipment.

The following are recommendations regarding operability aspects of equipment employing precoat filtration. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of equipment testing when the testing is done under the ETV Program.

During Verification Testing and during compilation of historical equipment operating data, attention shall be given to equipment operability aspects. Among the factors that should be considered are:

- fluctuation of body feed rate from desired value -- the time interval at which re-setting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?)
- can feed water flow rate be held constant even though head loss builds up during filter run?
- ease with which body feed rate can be checked
- can filter cleaning be done automatically?
- if automatic cleaning is provided, could it be initiated by:
- reaching a set value for head loss?
- reaching a set value for filtered water turbidity?
- does remote notification to operator occur when cleaning happens?
- can operator observe filter septa after cleaning?
- how can plant operator check on condition filter cake after precoating?
- can both influent pressure and effluent pressure be measured at filter vessel?
- is rate of flow of raw water measured?
- is filter aid body feed paced with raw water flow?
- is recirculation of filtered water provided for times of low flow?
- can volume of water used for cleaning filter be measured?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Task 3: Documentation of Operating Conditions and Treatment Equipment Performance, in the Precoat Filtration Test Plan.

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Table 1. Generic Schedule for Verification Testing		
Test Period	Initial Operations, Estimated Time	Verification Testing, Minimum Required Time
#1, required	1 - 6 weeks	272 hours
#2, optional	1 - 3 weeks	272 hours
#3, optional	1 - 3 weeks	272 hours
#4, optional	1 - 3 weeks	272 hours

Table 2. Water Quality Sampling and Measurement Schedule	
Sample or Measure For:	Minimum Frequency
Temperature	Daily
pH	Weekly - desired but optional
Total alkalinity	Weekly - desired but optional
Hardness	Weekly - desired but optional
Dissolved oxygen	Daily (for vacuum filters only)
Total organic carbon	Weekly - desired but optional
Turbidity, feed water	Intervals of 4 hours or less
Continuous turbidity monitoring, filtered water (and feedwater, if used)	Use data at 1/4, 1/2, or 1 hour intervals for calculation of long-term performance. Also note maximum turbidity observed each day.
Iron	Weekly
Manganese	Weekly if present in concentration of 0.05 mg/L or greater
Algae, number and species	Weekly if no algae bloom; Daily if algae bloom occurs.
Microscopic particulate analysis	As needed for diagnosis of short filter runs
Total coliform	Every other day for feed water and filtered water characterization - desired but optional.
UV_{254} absorbance	Weekly when sample for TOC taken - desired but optional.
Particle Counting	See Task 4.

Table 3. Analytical Methods			
Parameter	Facility	*Standard Methods*[1] number or Other Method Reference	EPA Method[2]
Temperature	On-Site	2550 B	
pH	On-Site	4500-H^+ B	150.1 / 150.2
Total alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Total organic carbon	Lab	5310 C	
Turbidity	On-Site	2130 B / Method 2	180.1
Particle counts (electronic)	On-Site	Manufacturer	
Dissolved Oxygen	On-Site	4500-O	
Iron	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Manganese	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Algae, number and species	Lab	10200 and 10900	
Microscopic particulate analysis	Lab		EPA 910-R-96-001
UV_{254} absorbance	Lab	5910 B	
Total coliform	Lab	9221 / 9222 / 9223	
E. Coli	Lab	9221 / 9222 / 9223 (Colilert)	
Bacillus spores	Lab	Rice et al. 1996	
MS2 virus	Lab		EPA ICR Method for Coliphage Assay, 1996
Microsphere counts	Lab	Li *et al.*, 1997	

Notes:
1) *Standard Methods* Source: 20th Edition of Standard Methods for the Examination of Water and Wastewater, 1999, American Water Works Association.
2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Table 4. Equipment Description and Operating Data	
Operating Data	Action
Feedwater Flow and Filter Flow	Check and record each two hours, adjust when >10% above or below goal. Record both before and after adjustment. (If filter operates on a declining rate principle, note flow through filter every two hours but do not adjust flow rate.)
Filtration Rate	Calculate based on flow rate data and run times.
Filter Precoating	Record quantity of filter media (diatomaceous earth or perlite) used to coat filter, for each precoating. (Volume of slurry used and concentration of filter media in slurry). Record grade and brand.
Body Feed	Record body feed slurry concentration when body feed slurry prepared and record flow rate for body feed at least once each eight hours. Record grade and brand.
Filter Head Loss (filter inlet pressure and filter outlet pressure)	Record initial clean bed total head loss at start of filter run and record total head loss each two hours.
Filter Run Length	Calculate based on starting time and ending time for each filter run.
Filtered Water Production	Calculate gallons of water produced per square foot of filter area (or m^3/m^2), for each filter run.
Filter Aid Usage	Using data for precoating and body feed and for water production, calculate total pounds or kilograms of filter aid used in each run and total filter aid usage expressed as mg/L.
Filter Cleaning	Record time and duration of each filter cleaning. Record water volume used to clean filter.
Electric Power	Record meter reading once per day
Hours operated per day	Record in log book at end of day or at beginning of first shift on the following work day.
Log of events in watershed	Record occurrence of storms, construction activity, snowmelt, or other activities that could influence source water quality in log book at end of day or at beginning of first shift on the following work day.
Provide complete description of precoat filtration plant as required in Task 3.	
All parameters will be checked only during times when the equipment is staffed.	

Table 5. Precoat Filtration Challenge Tests Using Microorganisms and Surrogates	
Microorganism	Surrogate
Giardia cysts	use *Cryptosporidium* surrogate because *Cryptosporidium* is a somewhat smaller protozoan organism
Cryptosporidium oocysts	3 to 5 μm microspheres
Bacteria	*E. coli*
	Total coliform bacteria
	Bacillus bacteria
Human Enteroviruses	MS2 coliphage
Sampling Schedule for Microorganisms and Surrogates	
Microspheres and Microorganisms	Take samples at time zero (as defined in Task 4), at 0.5 hr and at 1.0 hr past time zero, and at a time when head loss is estimated to be between 85% and 95% of terminal head loss.
Particle counting	Filtered water analyzed by flow-through particle counter. Feed water analyzed at least once per hour if using batch samples, or use flow-through particle counter.

CHAPTER 6

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN
BACKWASHABLE DEPTH FILTRATION FOR THE REMOVAL OF MICROBIOLOGICAL AND PARTICULATE CONTAMINANTS

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for evaluation of water treatment equipment utilizing backwashable depth filtration. This Testing Plan is to be used as a guide in the development of the Product-Specific Test Plan for testing backwashable depth filters, within the structure provided by the document, "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies."

The procedures and methods described in this test plan and in the referenced ETV Protocol Document shall be used as guidelines for the development of the Product-Specific Test Plan. The procedures and methods shall generally follow those Tasks related to Verification Testing that are outlined herein, with changes and modifications made for adaptations to specific backwashable depth filtration equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

- Introduction;
- Objectives;
- Work Plan;
- Analytical Schedule;
- Evaluation Criteria.

Each Product-Specific Test Plan shall include Tasks 1 through 6 as described later in this document.

2.0 INTRODUCTION

Water treatment equipment employing backwashable depth filtration is used primarily for removal of *Giardia* and *Cryptosporidium* from surface waters, as well as for removal of turbidity and other particulate matter. In some cases, clarification processes may be used to pretreat water at backwashable depth filtration plants.

This Equipment Verification Testing Plan is applicable to the testing of water treatment equipment utilizing a backwashable depth filtration process train. Two phases of testing are discussed. The first phase is Initial Operations, which consists of a series of tests that will be used by the Field Testing Organization to determine the optimum treatment scheme and most appropriate testing schedule at the specific geographical location or locations where testing is carried out. The second phase is Verification Testing, which will evaluate performance of the equipment under a range of raw water quality conditions. Verification Testing will be done during one or more periods when the source water or feed water quality is appropriate for testing the range of water quality conditions that need to be evaluated. Development and execution of well-documented testing covering a wide range of water quality conditions has a better chance of minimizing subsequent on-site testing which states may require before approving use of the equipment at specific locations.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analytical work to be carried out as a part of this Verification Testing Plan will be contracted with a state-certified or third party- or EPA-accredited laboratory.

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the recommended tasks that may be included in Initial Operations and of the required and optional tasks to be included in the backwashable depth filtration Verification Testing program. Tasks A and B are sequential tasks done before Verification Testing. Tasks 1 through 6 are to be done during Verification Testing and have overlapping time frames.

4.1 Task A: Characterization of Feed Water

The objective of this Initial Operations task is to obtain a chemical, biological and physical characterization of the feed water. A description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization.

4.2 Task B: Initial Tests Runs

During Initial Operations, the operating conditions that result in effective treatment of the feed water should be evaluated, along with equipment performance, particularly with regard to rate of head loss increase and turbidity or particle breakthrough. This is a recommended Initial Operations task.

4.3 Task 1: Verification Testing Runs

Water treatment equipment shall be operated for a period of 30 days, or longer, during one or more testing periods to collect data on equipment performance and water quality for purposes of performance verification.

4.4 Task 2: Feed Water and Finished Water Quality

During Verification Testing, feed water and treated water samples shall be collected, and appropriate sample analysis shall be undertaken, including turbidity measurement and particle counting.

4.5 Task 3: Operating Conditions and Treatment Equipment Performance

During each day of Verification Testing, operating conditions and performance of the water treatment equipment shall be documented. Operating conditions include filtration rate and filter headloss. Equipment performance includes rate of filter head loss gain and length of filter run.

4.6 Task 4: Microbiological Contaminant Removal

The objective of this task is to evaluate removal of microbiological contaminants or surrogates during Verification Testing by measuring removal of protozoan-sized particles naturally present in the feed water or by evaluating removal of protozoa or protozoan-sized particles seeded in the feed water, or by undertaking a combination of the above techniques.

4.7 Task 5: Data Management

The objectives of this task are to establish an effective field protocol for data management at the field operations site and for data transmission between the Testing Organization and the NSF for data obtained during the Verification Testing and to develop statistical analyses of certain test data.

4.8 Task 6: QA/QC

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during backwashable depth filtration equipment Verification Testing.

5.0 TESTING PERIODS

The required tasks in the Verification Testing Plan (Tasks 1 through 6) are designed to be carried out over one or more testing periods of 30 days or longer, not including mobilization, start-up, and Initial Operations. Each testing period should, if possible, include a minimum of three complete filter runs. At least two complete runs must be carried out, even if this requires more than 30 days. A schedule describing the duration and initiation of each of the above tasks is provided in Table 1.

Additional verification testing periods may be necessary to verify the manufacturer's objectives, such as in the treatment of surface water where additional testing during each season may assist in verifying an objective. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's objectives. For example, a good challenge for a backwashable depth filter would be a testing period during which the feedwater exhibits high concentrations of particulate matter such as algae, particles consisting of plant material, or sediment that may rapidly clog such filters. Although one testing period satisfies the minimum requirement of the ETV Program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined in Initial Operations. Performance and reliability of the equipment shall be tested during verification testing periods at a minimum of 30 days. The purpose of the 30 day test period is to demonstrate the level of filtered water turbidity that the equipment can produce at the test site and could be helpful in showing whether changes in the pH of the feed water affect filter performance. The 30 day test period should also evaluate equipment performance under a range of circumstances including attainment of terminal head loss, backwashing, and starting new filter runs.

6.0 DEFINITIONS

Definitions that apply for backwashable depth filtration processes include:

6.1 Backwashable Depth Filter: A bag filter, cartridge filter, or granular media filter intended to filter uncoagulated water and to be backwashed when terminal head loss is attained or turbidity breakthrough occurs.

6.2 Bag Filter: A non-rigid fabric filter in which flow generally is from the inside of bag to the outside. One or more filter bags are contained within a pressure vessel. Bag filters generally do not employ any chemical coagulation, if pretreatment is employed. The pore sizes in the filter bags designed for protozoa removal generally are small enough to remove protozoan cysts and oocysts but large enough that bacteria, viruses and fine colloidal clays would pass through. Bag filters would be tested under this test plan only if a manufacturer produced a bag filter that was intended to be cleaned by backwashing rather than replaced when terminal head loss is attained.

6.3 Cartridge Filter: A rigid or semi-rigid self-supporting filter element in which flow generally is from the outside of the cartridge to the inside. One or more filter cartridges are contained within a pressure vessel. Cartridge filters generally do not employ any chemical coagulation, if pretreatment is employed. The pore sizes in the filter cartridges designed for protozoa removal generally are small enough to remove protozoan cysts and oocysts but large enough that viruses and fine, sub-micron colloidal clays would pass through. Cartridge filters would be tested in this plan only if the cartridge is designed to be backwashed rather than replaced when terminal head loss is attained.

6.4 Filtration: A process for removing particulate matter from water by passage through porous media.

6.5 Granular Media Filter: A deep bed filter containing fine granular media that is used to filter water that has not been coagulated. These filters rely on straining particles out of water in the fine pores of the filter media or on attachment of particles to the filter media.

7.0 TASK A: CHARACTERIZATION OF FEED WATER

7.1 Introduction

This Initial Operations task is needed to determine if the chemical, biological and physical characteristics of the feed water are appropriate for the backwashable depth filtration equipment to be tested. This task should be undertaken with great care, because of the possibly limited capability of backwashable depth filters to remove fine colloidal clays that cause turbidity in many surface waters and because feed waters having high concentrations of particulate matter such as algae, particles consisting of plant material, or sediment might rapidly clog such filters, necessitating frequent backwashing of clogged filters.

If the source water used as feed water for the testing program has an excessive amount of the fine turbidity-causing particles, these filters may not be able to produce filtered water turbidity which meets the manufacturer's performance objectives. Because backwashable depth filters are not intended to remove viruses, the entire burden of virus control falls on the disinfection process when

these filters are used for water treatment. Excessive turbidity in filtered water could present problems in attaining effective disinfection and would be a likely cause for rejection of backwashable depth filters by drinking water regulators.

If the source water used as feed water consistently has a very low turbidity and very low concentration of algae and other particulate matter, drinking water regulators may be reluctant to approve backwashable depth filters for applications in which the source water turbidity or particulate matter concentration is higher. The feed water quality chosen for Verification Testing can influence both performance of the filtration equipment and the usefulness of testing results by verification report readers.

7.2 Objectives

The objective of this task is to obtain data from one or more years for the chemical, biological, and physical characterization of the source water or the feed water that will be entering the treatment system being tested. Factors of particular interest include conditions that affect filter run lengths, such as turbidity in runoff events following heavy rainfall or snowmelt, or algae blooms.

7.3 Work Plan

This task can be accomplished by compiling data obtained from third party sources (i.e. USGS, USEPA, State Laboratories, Municipal Laboratories). The specific parameters needed to characterize the water will depend on the equipment being tested but information on the following characteristics should be compiled:

- Turbidity, Algae, Temperature, and pH
- Total Coliform, Total Alkalinity, Hardness, TOC, and True Color
- Total Suspended Solids

Sufficient information shall be obtained to illustrate the timing and degree of variations expected to occur in these parameters that will be measured during Verification Testing. This information will be compiled and shared with NSF so NSF and the Field Testing Organization can determine the adequacy of the data for use as the basis to make decisions on the testing schedule. Failure to adequately characterize the feed water (source water) could result in testing at a site later being deemed inappropriate, so the initial characterization will be important to the success of the testing program. Seasonal as well as potential daily variations in water quality should be considered in the evaluation of feed water data.

A description of the watershed that provides the feed water shall be provided, to aid in interpretation of feed water characterization. The watershed description should include a statement of the approximate size of the watershed, a description of the topography (i.e. flat, gently rolling, hilly, mountainous) and a description of the kinds of human activities that take place (i.e. mining, manufacturing, cities or towns, farming) or animal activities with special attention to potential sources of pollution that might influence feed water quality. The nature of the water source, such as stream, river, lake, or man-made reservoir, should be described as well.

7.4 Analytical Schedule

In many cases, sufficient water quality data may already exist to permit making a determination of the suitability of a source water for use as feed water in a backwashable depth filtration Verification Testing program. Table 2 of this chapter gives examples of the kinds of data and the frequency of analysis that could be helpful when making an evaluation of source water quality.

7.5 Evaluation Criteria

Feed water quality will be evaluated in the context of the Manufacturer's statement of performance objectives. If the turbidity of the feed water is substantially greater than 1 nephelometric turbidity unit (NTU) and periodically exceeds 5 NTU, producing filtered water with an acceptable turbidity may be difficult, depending on the size of the particulate matter causing the turbidity. The feed water should challenge the capabilities of the equipment but should not be beyond the range of water quality suitable for treatment by the equipment in question.

8.0 TASK B: INITIAL TEST RUNS

8.1 Introduction

During Initial Operations, a Manufacturer may want to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water. This is a recommended Initial Operations task and may occur during each of the periods in which Verification Testing is to be done. Initial test runs are required before the start of the first period of Verification Testing so an NSF field inspection of equipment operations and sampling and field analysis procedures can be carried out during the initial test runs.

8.2 Objectives

The objective of these test runs is to assess filter run length to permit planning for challenge tests and sampling during Verification Testing. Therefore, conducting initial test runs for each testing period is strongly recommended. Testing may also be needed to demonstrate the level of filtered water turbidity that the equipment can produce at the test site and could be helpful in showing whether changes in the pH of the feed water affect filter performance.

8.3 Work Plan

Initial tests for backwashable depth filtration are to be conducted using the filtration equipment that would be used for Verification Testing, so a preliminary assessment of treatment performance can be made, especially for filter run length. During exploratory tests, information also can be developed on the extent of turbidity removal that can be accomplished when treating the source water.

8.4 Analytical Schedule

Because these runs are being conducted to determine the suitability of the technology for Verification Testing, a strictly defined schedule for sampling and analysis does not need to be followed. Adhering to the schedule for sampling and analysis to be followed during Verification Testing would be wise, however, so the operator can gain familiarity with the time requirements that will be

applicable later on in the test program. Also, during the Initial Operations phase, NSF will be conducting an initial on-site inspection of field operations, sampling activities, and on-site sample analysis. The on-site inspection will cover activities such as those described in Task 5: Data Management, and Task 6: QA/QC. During the on-site inspection the FTO should be prepared to demonstrate how appropriate data management and QA/QC procedures are being applied. The sampling and analysis schedule for Verification Testing shall be followed during the on-site inspection.

8.5 Evaluation Criteria

The Manufacturer should evaluate the data produced during the Initial Operations to determine if the water treatment equipment performed so as to meet or exceed expectations based on the statement of performance objectives with regard to water quality. If the performance was not as good as the statement of performance objectives, the Manufacturer may wish to conduct more Initial Operations or to cancel the testing program.

9.0 TASK 1: VERIFICATION TESTING RUNS AND ROUTINE EQUIPMENT OPERATION

9.1 Introduction

Water treatment equipment employing backwashable depth filtration shall be operated for Verification Testing purposes, with the approach to treatment based on the results of the Initial Operations testing.

9.2 Experimental Objectives

The objective of this task is to operate the treatment equipment provided by the Manufacturer for one or more periods of 30 days or longer and to evaluate equipment performance under a range of circumstances including attainment of terminal head loss, backwashing, and starting new filter runs.

9.3 Work Plan

The Verification Testing Runs in this task consist of continued evaluation of the treatment system, using the most successful treatment parameters defined in Initial Operations. To obtain a perspective on the overall performance of the backwashable depth filter, one or more Verification Testing periods, each lasting for a minimum of 30 days, are anticipated for evaluating the performance of a treatment system. During each testing period, the filter shall be operated and backwashed, and then it should be run through at least two cycles involving operation and backwashing. If this can be done within 30 days, Verification Testing should be conducted under conditions likely to provide a wide range of feed water quality for testing purposes. During each testing period, Tasks 1 through 6 shall be conducted simultaneously.

Testing over a range of feed water quality is recommended because of the differences in water quality that occur on a seasonal basis or at different locations. For backwashable depth filtration treatment equipment, factors that can influence treatment performance include:

- high turbidity, often occurring in spring, encountered in rivers carrying a high sediment load or in surface waters during periods of high runoff resulting from heavy rains or snowmelt
- algae, which may exhibit blooms on a seasonal basis in spring, summer or fall
- lake or reservoir turnover, if this results in iron, manganese, or bottom sediments being carried up closer to the surface where they enter the source water (feedwater) intake
- temperature
- diurnal pH changes
- natural organic matter due to runoff
- feed water disinfection

It is highly unlikely that all of the above problems would occur in a surface water during a single testing period, and this results in the recommendation for multiple testing periods or multiple sites or both to capture critical events that affect water quality.

9.4 Schedule

During Verification Testing, water treatment equipment shall be operated for a minimum of 30 days. Backwashable depth filtration treatment equipment shall be operated from start-up until turbidity breakthrough or terminal head loss is attained. When turbidity breakthrough terminal head loss is attained, the filter shall be backwashed, and operation shall resume. The testing shall include as many cycles of filtration and backwashing as can be accomplished in the 30 days of equipment operation, but a minimum of two cycles of backwashing a dirty filter and operating the filter after backwashing shall be accomplished in each testing period, even if this requires more than 30 days of operation.

Filter runs shall not be terminated and the filter backwashed before turbidity breakthrough or terminal head loss except because of equipment failure or power interruption because data on complete filter runs are needed to fulfill the objectives of Verification Testing. If the water treatment equipment can be stopped and restarted without being backwashed, then this aspect of equipment operation shall be evaluated during routine Verification Testing and during the challenge tests described in Task 4. During routine Verification Testing filtration shall be stopped and restarted without backwashing once per day, three days per week (only if the equipment can be operated in this manner) because intermittent, stop-start operation is commonly practiced by many small water systems.

The duration of each filter run and the number of gallons of water produced per square foot (or cubic meters of water produced per square meter) of filter area or the volume of water produced by a specific model of a backwashable depth filter shall be recorded in the operational results.

9.5 Evaluation Criteria

The goal of this task is to operate the equipment for the 30-day period, or longer, during Verification Testing, and to collect data on at least two cycles involving backwashing a dirty filter and operating it to terminal head loss after it was backwashed. Data shall be provided to substantiate the operation for 30 days or more.

10.0 TASK 2: TEST RUNS FOR FEEDWATER AND FINISHED WATER QUALITY

10.1 Introduction

Surface waters of high quality are the most appropriate waters for treatment by backwashable depth filtration equipment. Characterization of the feed water is very important, as feed water quality can strongly influence the performance of this equipment. Backwashable bag and cartridge depth filters function by straining, so a mat or cake builds up on the filter surface and in the pores of the filter medium. If the materials being removed are incompressible, such as hard, mineral materials, the build-up of this cake may not hinder filtration seriously. On the other hand, removal of compressible particles such as algae or fragments of biological matter can cause the filter to become blinded. This might lead to unacceptably short filter runs. Turbidity of a source water may not be an adequate indicator of its suitability for treatment by these filters. The volume of water that can be filtered could vary by a factor of ten fold or greater for water of a given turbidity, depending on the nature of the particulate matter in the raw water because turbidity cannot indicate whether particles are compressible or incompressible. The recommended and required water quality data and sampling schedule for feed water and filtered water quality are given in Table 2. Water quality goals and target removal goals for the water treatment equipment shall be recorded in the Product-Specific Test Plan in the statement of objectives.

10.2 Experimental Objectives

A list of recommended and required water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 2. The actual water quality parameters selected for testing shall be stipulated in the Product-Specific Test Plan and shall include all those necessary to permit verification of the statement of performance objectives. If the water being filtered tends to cause rapid increases in head loss, efforts should be made to identify the nature of the particulate matter that is causing the rapid clogging.

The characterization of feed water is intended to provide sufficient information to enable State drinking water regulators to compare the quality of the feed water used in Verification Testing with the quality of source water at a site where the use of the equipment may be proposed.

10.3 Work Plan

The manufacturer will be responsible for establishing the filtration equipment operating parameters, on the basis of the initial test runs. The backwashable depth filtration equipment shall be operated continuously until turbidity breakthrough or terminal head loss occurs, unless operation is stopped and restarted for a microsphere challenge test or for routine evaluation of the effect of stopping and restarting without backwashing. When turbidity breakthrough or terminal head loss is reached, the filter shall be backwashed and filtration operations shall be resumed. This shall continue until the end of the 30-day period, or for a longer period if needed to attain two complete cycles of operation involving backwashing a dirty filter and then running until terminal head loss is reached.

Many of the water quality parameters described in this task will be measured on-site by the Field Testing Organization. Analysis of the remaining water quality parameters will be performed by a state-certified or third party- or EPA-accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field will be described in the Analytical Methods

section below and in Table 3. The analytical methods utilized in this study for on-site monitoring of feedwater and filtered water qualities are described in Task 6, Quality Assurance/Quality Control (QA/QC). Where appropriate, the *Standard Methods* reference numbers for water quality parameters are provided for both the field and laboratory analytical procedures. One analytical procedure that is not required but which can prove helpful if excessive clogging of the filters is encountered is the Microscopic Particulate Analysis (MPA) for Filtration Plant Optimization (EPA 910-R-96-001.) Use of MPA for assessing filtration performance was recently described (Hancock et al. 1996).

10.3.1 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during each period of filtration testing, as noted in this section. Additional sampling and data collection may be performed at the discretion of the Manufacturer. Sample collection frequency and protocol shall be defined in the Product-Specific Test Plan.

In the case of water quality samples that will be shipped to the state-certified or third party- or EPA-accredited analytical laboratory for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the state-certified or third party- or EPA-accredited analytical laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory.

10.4 Analytical Schedule

During Verification Testing for backwashable depth filtration treatment equipment, the feed water (raw water) quality and filtered water quality shall be characterized by measurement of the following water quality parameters:

- temperature (daily)
- pH (weekly)
- total alkalinity (desired weekly but optional)
- hardness (desired weekly but optional)
- total organic carbon (desired weekly but optional)
- iron (once per test period if less than 0.3 mg/L, or weekly if above 0.3 mg/L in feed water)
- manganese (once per test period if less than 0.05 mg/L, or weekly if above 0.05 mg/L in feed water)
- algae, number and species (weekly, but three times per week if filter runs are shortened by presence of algae)
- UV_{254} absorbance (desired weekly but optional)
- total coliform bacteria (desired twice per week, with samples collected at least two days apart, but optional)
- turbidity (continuous for filtered water)
- particle counts (see Task 4)

If feed water quality changes significantly at some time between the intervals for which sampling is required, sampling after such a quality change could be beneficial to the testing program if the sample data demonstrated that a wider range of water quality could be successfully treated. Therefore in some circumstances it may be advisable to collect feed water samples more frequently than indicated above.

Turbidity of filtered water shall be measured and recorded using a continuous, flow-through turbidimeter. Turbidity of feed water (before seeding of microorganisms or microspheres) shall be measured continuously using a flow-through turbidimeter or at intervals of not more than four (4) hours if a bench model turbidimeter is used for grab samples. Continuous measurement of turbidity of feed water is preferred but not required. On a daily basis a bench model turbidimeter shall be used to check the continuous turbidimeter readings.

Particle counts of feed water and filtered water shall be measured and recorded using a particle counter equipped with flow through sensors capable of detecting particles as small as 2 μm in size.

The above water quality parameters are listed to provide verification report readers with background data on the quality of the feed water being treated and data on the quality of the filtered water. The required and recommended data are to be collected to enhance the usefulness of the Verification Testing data to a wide range of verification report readers.

10.5 Evaluation Criteria

Evaluation of water quality in this task is related to meeting general water quality capabilities indicated by the Manufacturer.

- Turbidity of filtered water equals or exceeds goals specified by the Manufacturer
- Water quality and removal goals specified by the Manufacturer

11.0 TASK 3: DOCUMENTATION OF OPERATING CONDITIONS AND TREATMENT EQUIPMENT PERFORMANCE

11.1 Introduction

During each day of Verification Testing, operating conditions shall be documented. This shall include descriptions of treatment processes used and their operating conditions. In addition, the performance of the water treatment equipment shall be documented, including filtration rate expressed as gallons per minute per square foot or rate of flow through the filter expressed as gallons per minute, rate of filter head loss gain, water pressure at the inlet and outlet of the backwashable depth filter pressure vessel, length of filter run and terminal head loss, and backwashing. Operating conditions are likely to be evaluated in great detail by state reviewers and are an important aspect related to approval of equipment.

11.2 Objectives

The objective of this task is to accurately and fully document the operating conditions that applied during treatment, and the performance of the equipment. This task is intended to result in data that describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

11.3 Work Plan

A complete description of each process in the treatment equipment shall be given. In addition if a roughing filter or other pretreatment not employing coagulation is used, that also shall be fully described. Data on the filtration equipment shall be provided and shall include the following:

- flow capacity and actual flow rate during operation, gallons per minute
- filtration rate in gallons per minute per square foot, for filters using granular filter media
- nominal pore rating of filter bag or filter cartridge and the method used to determine this pore rating if these filters are used; or the type of filtering material, effective size, uniformity coefficient, specific gravity, and depth for each layer used, if granular media filtering material is used
- number of filter bags or filter cartridges housed within the pressure vessel; or cross sectional area of filter vessel, if granular filter media is used
- maximum operating pressure of filter vessel
- volume of filter vessel
- the backwashing method and backwashing apparatus shall be fully described, including the total volume of backwash water to be used and the duration of backwash in minutes

In addition, system reliability features including redundancy of components, shall be described. Spatial requirements for the equipment (footprint) shall be stated. Some of the above requirements might be met by providing manufacturer's engineering drawings of the equipment used in Verification Testing.

During Verification Testing, backwashable depth filter operating parameters for filtration shall be monitored and recorded on a routine basis including rate of flow, filtration rate, pressure at filter vessel inlet and outlet, and maximum head loss. Every backwashing event shall be noted and recorded, and the volume of water used for each backwash shall be measured and recorded and the reason for backwashing noted. Electrical energy consumed by the treatment equipment shall be measured, or as an alternative, the aggregate horsepower of all motors supplied with the equipment could be used to develop an estimate of the maximum power consumption during operation. Performance shall be evaluated to develop data on the number of gallons of water that can be produced during each filter run and on energy needed for operation of the process train being tested.

A daily log shall be kept in which events in the watershed are noted if they could influence source water quality. This includes such things as major storm systems, rainfall, snowmelt, temperature, cloud cover, upstream construction activities that disturb soil, failure or destruction of beaver dams, and intermittent operation of hydroelectric generating facilities.

11.4 Schedule

Table 4 presents the schedule for observing and recording backwashable depth filtration equipment operating and performance data.

11.5 Evaluation Criteria

Where applicable, the data developed from this task will be compared to statements of performance objectives. The quantity of water that is produced and meets quality criteria for acceptance will be an important factor in this evaluation.

If no relevant statement of performance capability exists, results of operating and performance data will be tabulated for inclusion in the Verification Report.

12.0 TASK 4: MICROBIOLOGICAL CONTAMINANT REMOVAL

12.1 Introduction

Removal of microbiological contaminants is a primary purpose of filtration of surface waters. Consequently, the effectiveness of backwashable depth filtration treatment processes for microbial removal will be evaluated in this task. Assessment of treatment efficacy will be made on the basis of testing for removal of protozoan microorganisms or by particle counting and removal of microspheres, depending on the particle removal mechanism by which the filter is expected to work. Filter backwashing typically requires some expansion of the pore structure in the filter so trapped particles can be freed and washed out of the filter. Therefore testing for removal of protozoa or of microspheres in multiple filter cycles is an important part of the evaluation of filter efficacy for these filters.

Backwashable depth filtration based on cartridge filters or bag filters would remove particles, including microorganisms, in the size range of *Giardia* and *Cryptosporidium* from water by physically straining out the particles and trapping them within the filter. This filtering mechanism requires the pore structure in the medium to be sufficiently fine to trap particles as small as 3 μm, for control of *Cryptosporidium*. The key role of physical straining for particle removal results in microspheres being appropriate surrogates for oocysts. Backwashing bag or cartridge filters would loosen or enlarge the pore structure of the filter bags or cartridges, and this would cause the absolute pore size of the filter medium to be known with less certainty. Therefore at least some of the surrogate particles used in testing should be as small as the smallest *Cryptosporidium* oocysts, which are about 3 μm in size. Microspheres used as surrogates shall be 3 to 7 μm in diameter. Microspheres in this size range can be obtained by ordering batches of microspheres in two or more sizes. At least 50% (by number or count) of the microspheres used in challenge tests must be in the 3 to 4 μm size range.

Backwashable depth filtration based on using fine granular media could work in two ways, straining and surface attachment. If the media were sufficiently small, the pore spaces in the media would be small enough to strain out particles such as *Cryptosporidium*. It can be shown mathematically that for three equal-sized spheres which are all touching, the largest sphere that can pass through the pore space or void space between the three spheres is a sphere having a diameter that is 15.47% of the diameter of the three larger spheres. Therefore for a straining mechanism to attain complete removal of *Cryptosporidium* oocysts as small as 3 μm, spherical granular filter media would need to be 20 μm (0.020 mm) in size. For spherical granular media larger than 20 μm, some straining action could occur at sites close to where larger media granules touch, but the voids or pores between the granules would be large enough to permit passage of 3 μm particles. Mathematical analysis of the relationship of particle sizes and pore sizes of non-spherical media would be extraordinarily complex, especially for angular media such as crushed anthracite or irregularly shaped media such as diatomaceous earth, and that analysis will not be attempted in this document. This analysis is presented to demonstrate that for granular media, as the size of the media grains becomes larger with respect to the size of the particle to be removed, opportunities for particle removal by straining are reduced. For the relationship of particle size to filter material size to be known, the size distribution of the filter media must be determined, as described in Task 3.

Another mechanism by which small particles can be removed in granular media filters is surface attachment. Commonly accepted filtration theory holds that for surface attachment mechanisms to function, the repulsive forces acting between the particles being removed and the filter media must be overcome. The usual means of promoting the surface attachment mechanism is to coagulate water so the negative surface charges on particles in water can be reduced or mitigated, which then enables the surface attachment to occur more readily. Coagulation can facilitate the attachment of very small particles such as bacteria, asbestos fibers, or viruses to filter media grains that are as much as 1000 times (or more) larger than the particles being removed, when coagulant dosages are such that the mode of removal is by particle destabilization rather than sweep floc removal.

When coagulant chemicals are not used, particle removal by surface attachment can still occur, but the repulsive forces acting between the removed particle and the filter grains would be greater than if coagulation had been practiced. For non-coagulated particles to be held on filter grains, the attractive forces must be greater than the repulsive forces, but the net attractive force would be less because of the absence of coagulation. Therefore non-coagulated particles would be expected to be held less securely, and they may be more susceptible to being removed from the filter grains by shear forces caused by water velocity within the granular media filter bed.

If surface attachment is believed to have a role in particle removal in granular media backwashable depth filters, testing for removal of *Cryptosporidium* oocysts or *Giardia* cysts would need to be conducted with those organisms, because of the importance of the role of surface charge of the particles being removed. Use of microspheres as surrogates would be acceptable only if the role of surface attachment was negligible or if the surface charge (zeta potential or electrophoretic mobility) of the surrogate and the specific gravity of the surrogate were very similar to those properties for the oocysts or cysts. Until such a determination can be made, testing for granular media backwashable depth filters should be done with oocysts and cysts if surface attachment mechanisms are involved in protozoa removal.

If manufacturers provide an explanation of the particle removal mechanisms that take place in their backwashable depth filtration equipment, this may aid states in evaluating the results of Verification Studies. Providing such an explanation, however, is not a requirement of this test plan.

Removal of turbidity by backwashable depth filters is not synonymous with removal of protozoan organisms because turbidity-causing particles can be much smaller than protozoa. This can result in backwashable depth filters being able to remove protozoan-sized particles while passing particles in the size range of bacteria and viruses, or the micron-sized and sub-micron-sized particles that cause turbidity. Therefore turbidity removal is not a surrogate for protozoan removal in backwashable depth filtration. Turbidity of filtered water, however, has regulatory implications. Therefore it is important to be able to satisfy filtered water turbidity requirements set forth by the U.S. EPA or by the individual states.

Use of electronic particle counting to assess protozoan removal by backwashable cartridge filters or bag filters would be appropriate only for feed waters containing large numbers of particles in the size range of *Cryptosporidium*. The pore structure of backwashable depth filters using bags or cartridges as the filter medium would be changed during backwashing to facilitate removal of trapped particles, so particles in the size range for *Cryptosporidium* oocysts, i.e. 7 μm shall be counted. In addition, particles larger than 7 μm shall also be counted. If sufficient concentrations of 7 μm sized particles

are not naturally present in the feed water, use of electronic particle counting may not be capable of demonstrating adequately high log removals without seeding of microspheres in the 7 μm size range.

12.2 Experimental Objectives

For granular media backwashable depth filters the objective of this task is to evaluate removal of particles and microbiological contaminants during Verification Testing by measuring removal of microorganisms seeded into the feed water. For backwashable cartridge or bag filters the objective of this task is to evaluate removal of particles and microbiological contaminants by assessing removal of polystyrene fluorescent microspheres and particles, with use of seeded microorganisms an optional means of evaluating those filters.

12.3 Work Plan

Task 4 shall consist of particle counting and tests involving seeded microspheres, with optional use of seeded *Cryptosporidium* oocysts for evaluation of backwashable bag filters or cartridge filters. For evaluation of microorganism removal by backwashable depth filters using granular filter media, seeded *Cryptosporidium* oocysts shall be used if the filtration equipment is intended to remove *Cryptosporidium*. The additional cost of evaluating *Giardia* cyst removal is not great when *Cryptosporidium* seeding is being done, so manufacturers are encouraged to include *Giardia* cyst seeding when *Cryptosporidium* seeding challenge studies are being done. Inclusion of *Giardia* would provide data to support statements of performance capability for *Giardia* in addition to *Cryptosporidium*, for backwashable depth filters using granular media.

12.3.1 Seeding Technique

The purpose of this task is evaluation of the backwashable depth filter for microorganism removal, so any seeding of *Cryptosporidium* (or of *Cryptosporidium* and *Giardia*) or microspheres shall be done just prior to the entry of the water into the backwashable depth filtration equipment. Seeded organisms or microspheres shall be mixed (preferably by a static in-line mixer) prior to flowing into the filtration equipment. During seeding tests, the concentrated suspension of microspheres or microorganisms shall be gently stirred to maintain the particles in suspension. The concentrated microspheres shall be suspended in a solution of distilled or deionized water with 0.01% Tween 20. Microorganisms shall be suspended in distilled or deionized water with no wetting agents or detergents because of the possibility of interference with attachment of microorganisms onto granular media in depth filters. Before each run with seeded microspheres, the holding vessel shall be washed with hot water and laboratory glassware detergent and thoroughly rinsed with tap water or filtered water. The suspension shall be kept chilled during seeding. Microspheres or microorganisms shall be added to the feed water using a variable speed chemical feed pump. The preferred method of mixing of seeded microspheres or microorganisms into the feed water is with an in-line mixer that attains a head loss of about 0.3 to 0.5 feet of water during operation. Seeding of microspheres on a continuous basis shall be done for a minimum time consisting of the time needed for displacement of three volumes, i.e. three theoretical detention times, of the filter vessel plus 60 minutes. Seeding by a slug dose method shall be done in the shortest practicable time.

12.3.2 Electronic Particle Counting

When an electronic particle counter is used for evaluation of particle removal by backwashable bag or cartridge filters, particle counts in the feed water after mixing but just before entry into the backwashable depth filter shall be measured to determine the concentration of particles before filtration, and particle counts in the filtered water shall be measured. For assessing *Cryptosporidium* oocyst removal by particle counting, particles in the size range of 3 μm to 7 μm shall be counted. If appropriately sized particles are not present in sufficient densities (concentrations) in the feed water to permit calculation of log removals consistent with the Manufacturer's statement of performance capability, then particle counting for log removal should be done during microsphere challenge events.

12.3.3 Microspheres

Evaluation of microsphere removal by backwashable bag or cartridge filters shall be conducted by measuring the density (or concentration) of microspheres seeded on a continuous basis in the feed water and then measuring the density (or concentration) of microspheres in the filtered water or by determining the number of microspheres added to the feed water in a slug dose and then measuring the total number of microspheres detected in the filtered water. Microspheres used as surrogates for *Cryptosporidium* oocysts shall be 3 to 7 μm in diameter. Microspheres in this size range can be obtained by ordering batches of microspheres in two or more sizes. At least 50% (by number or count) of the microspheres used in challenge tests must be in the 3 to 4 μm size range.

The number of microspheres used shall be sufficient to permit calculation of log removals that exceed the removal capability as set forth in the Manufacturer's statement of performance objectives. Recovery of microspheres in filtered water provides data for use in calculating definite removal percentages, in contrast to the practice of reporting removals that exceed a specified value based on the detection limit, which would have to be done when no microspheres are detected in filtered water. For testing involving microscopic enumeration, fluorescent microspheres and an optical microscope equipped with ultraviolet illumination shall be used.

If microspheres are seeded into the feed water on a continuous basis, determination of microsphere density by means of electronic particle counting may be feasible, depending on the statement of performance related to the log removal that can be attained by the filtration equipment and depending on the density (concentration) of microspheres that can be seeded into the feed water. Density (concentration) of microspheres will be a function of the rate of flow of feedwater, the total number of microspheres available for seeding, and the length of time seeding occurs. If electronic particle counting is not feasible, enumeration of microspheres in feed water and filtered water by optical microscopy shall be required.

Two techniques for microscopic analysis of water samples containing fluorescent microspheres may be used. One is the method used by Abbaszadegan *et al*. (1997) for enumeration of *Giardia* cysts and *Cryptosporidium* oocysts, and the other is the method of Li *et al*. (1997) which they used for enumeration of microspheres.

If the techniques for microsphere sampling and enumeration are based on the research work of Li *et al.* (1997) which was carried out at the U.S. EPA's research laboratory in Cincinnati, the procedures below shall be followed. Additional details may be obtained from Li (1994).

Samples of feed water seeded with microspheres and samples of filtered water shall be filtered through 1 μm pore size, 293 mm diameter polycarbonate membranes. A stainless steel filter manifold shall be used to support the polycarbonate membrane. Volume of water filtered, and the times of initiation and completion of filtration shall be noted. The filter shall be removed from the manifold and placed in a container specified by the analytical laboratory, and refrigerated until shipped to the EPA-accredited analytical laboratory. At the analytical laboratory the microspheres removed from the filter with a laboratory squeegee and by washing with about 200 mL of 0.01% Tween 20. The liquid and particulate matter removed from the membrane shall be concentrated to a volume of between 1 and 10 mL by means of centrifugation for 10 minutes at 1200 x gravity. The volume of the concentrated suspension shall be recorded. Microspheres shall be enumerated using a hemacytometer under a UV microscope at 400 magnification. A minimum of three hemacytometer counts shall be performed for each sample. The volume of suspension examined in the hemacytometer shall be recorded and used to determine the fraction of the original water sample which was ultimately examined under the microscope.

Standard Methods states that hemacytometer chambers come with detailed manufacturer's instructions concerning calculations and proper usage. *Standard Methods* contains the precaution that disadvantage of hemacytometers is that the sample must have a very high density of objects being counted in order to yield statistically reliable data. Some exploratory tests may be needed to identify appropriate volumes of treated water to filter through the polycarbonate membrane or appropriate densities (concentrations) of microspheres in the seeded feed water, so that reliable statistics can be attained in filtered water analysis. The total number of microspheres counted in the hemacytometer should be between 30 and 300 to obtain good statistical results without counting overwhelming numbers of microspheres.

If the entire flow stream produced by the backwashable depth filtration equipment can not be filtered through the 293 mm membrane filter for sampling, a measured portion of the total filtered water flow can be sampled as it is produced, or the entire flow of filtered water from a seeding test can be stored in a biologically inert clean vessel and later filtered through the 293 mm membrane filter at a rate of flow suitable for the membrane filter.

If an instantaneous slug dose of microspheres is applied and the entire volume of filtered water is saved in a biologically inert storage vessel for subsequent membrane filtration as the sampling procedure, a volume of filtered water of at least 20 times the volume of the of the water in the filter's pressure vessel shall be filtered through the backwashable depth filter and saved for sampling and analysis. The volume of the water in a filter vessel may be calculated by subtracting the volume of the filters and appurtenances in the vessel from the volume of the empty vessel or by carefully measuring the volume of water required to fill the pressure vessel of a filter with the appropriate number of bags or cartridges installed and ready for use.

12.3.3.1 Organisms Employed for Challenge Tests. Microbiological testing of backwashable depth filters employing granular filter media shall be performed by seeding *Cryptosporidium* oocysts into the feed water and by analyzing for oocysts in the feed water and in the filtered water if the Manufacturer's statement of performance capability indicates

that *Cryptosporidium* can be removed by the filtration equipment. Test results (Clancy *et al*., 1993) indicate that *Giardia* removal by backwashable granular media depth filters may be greater than *Cryptosporidium* removal. The extra cost for seeding and analyzing for *Giardia* cysts is nominal when *Cryptosporidium* oocysts are being seeded, so some manufacturers may decide to include *Giardia* testing for backwashable depth filters employing granular filter media and provide testing data to support statements of performance related to removal of both *Cryptosporidium* and *Giardia*. If *Giardia* cysts are included along with *Cryptosporidium* in challenge studies, either *Giardia lamblia* or *Giardia muris* may be used, and the procedures described for the *Cryptosporidium* challenge shall be used for handling, seeding, and analyzing for both protozoa.

Cysts and oocysts shall be prepared and stored using techniques that minimize changes to the organisms to the extent practical. In particular, when cyst or oocyst removal is accomplished by surface attachment, changes in the zeta potential of the organisms should be avoided. Storage of oocysts should be in water, either with or without antibiotics added. Oocysts shall not be stored in a dichromate solution for preservation when they are to be used in challenge tests involving oocyst removal by surface attachment mechanisms. Oocysts should be less than 8 weeks old (less than 8 weeks from the date of shedding) when they are used. *Giardia* cysts should be less than 4 weeks old when used.

When testing is done with seeded oocysts, the oocysts shall be used in densities sufficient to permit calculation of at least 3-log removal, and seeding of microorganisms shall begin at start-up of the treatment equipment. The organism feed suspension will be prepared by diluting the organisms to be seeded into dilution water that is distilled or deionized and disinfectant free. The feed reservoir for the organism suspension shall be made of biologically inert material (i.e., not toxic to the organisms in the suspension.) The reservoir will be mixed continuously throughout the seeding experiment and kept packed in ice in a cooler. The seed suspension will be fed into the feedwater using an adjustable rate chemical feed pump. Mixing of this suspension with the feedwater will be accomplished using an in-line static mixer.

The analytical method required to be used for *Cryptosporidium* oocysts are EPA methods 1622/1623. If changes to the *Cryptosporidium* methods are tested, peer reviewed, evaluated by several laboratories, and then accepted by the U.S. EPA or are published by *Standard Methods*, the improved methods should be followed. Refer to www.epa.gov/nerlcwww/index.html for updates.

12.4 Analytical Schedule

12.4.1 Particle Counting

Analysis of feed water samples by electronic particle counters may be done on a batch or a continuous basis. If batch measurements are made, they shall be made for at least 8 hours each working day during Verification Testing, with samples collected and analyzed at least once each hour and in conjunction with microbiological challenges, microsphere challenges, and stop-start operations. Filtered water analysis shall be done using flow-through particle counters, equipped with recording capability so data can be collected on a 24-hour-per-day basis during Verification Testing.

On days when microsphere challenge tests or microbiological challenge tests are undertaken, particle counting activities shall be coordinated with the challenge test sampling activities so particle count data are available for every sample that is analyzed for microspheres or microorganisms. On days when challenge tests are not carried out, at least eight feed water samples shall be obtained for particle counting and for purposes of comparison with filtered water so calculation of log removal of particles can be done.

Special sampling and analysis shall be done to evaluate the effect of stop-start operations that are common in small systems. If the backwashable depth filtration equipment can be stopped and restarted without backwashing, particle count data shall be obtained for three feed water samples and for three filtered water samples during the last 30 minutes before the occurrence of the daily shutdown described in Task 1, Section 9.4, Schedule. After the filter has been restarted, filtered water particle count data shall be obtained for six samples collected at five-minute intervals during the first 30 minutes of operation after restart, and then three samples of feed water shall be analyzed for particle counts as soon as practical. If the equipment can not be stopped and restarted without backwashing, filtered water particle count data shall be obtained for six samples collected at five-minute intervals during the first 30 minutes of operation after backwashing and restart, for evaluation of the effects of backwashing and restarting the filter. If feed water particle counting is done on a continuous basis, comparable feed water data shall also be obtained.

12.4.2 Microsphere Samples and Microbiological Samples

During each Verification Testing period, the filter shall be operated and backwashed, and then it shall be run through at least two complete cycles involving operation to turbidity breakthrough or terminal head loss and backwashing, even if this evaluation requires more than 30 days. During the test period, two complete filter cycles or runs shall be subjected to challenge tests with microspheres for backwashable bag or cartridge filters or with protozoa for backwashable granular media filters.

If microbiological seeding is carried out, seeding and collection of microbiological samples shall be collected from feed water and filtered water on the same schedule stipulated for microsphere samples.

During each microsphere or microorganism challenge test run, microspheres or microorganisms shall be seeded three or four times during a run. Three of these times are at the start-up of the equipment after the filter was backwashed; near the middle of the run when head loss has approached one half of the recommended terminal head loss; and near the end of the run after head loss has reached 85 to 95 percent of recommended terminal head loss. In addition, if the filter can be stopped and restarted without backwashing, after the seeding challenge and sampling in the middle of the run has been completed, the filter flow shall be stopped and preparations shall be made for another round of sampling. The filter shall be restarted and sampling shall be done again, to evaluate the effect of stopping and starting a filter that has removed a very large number of microspheres or microorganisms. This stop-start test is required for evaluation of the potential effect of intermittent operation on water quality. Inclusion of a stop-start evaluation is not required if the equipment is designed and programmed to automatically backwash every time it is stopped and restarted. If stop-start operation with the equipment is appropriate and if filter runs are expected to be longer than about four days, the stop-start operations shall be conducted as described in Task 1, but only

one microsphere or microorganism challenge shall be conducted after filter restart, and this shall be done at about half of the recommended terminal head loss. The timing for challenge sampling events is presented in Table 5.

The timing for collection of samples may be different based on whether continuous seeding or slug dose seeding is used.

When microspheres or microorganisms are seeded on a continuous basis, the seeding shall be done for a duration of 1.0 hour, plus an amount of time equal to 3 theoretical detention times through the filter vessel at the rate of flow being tested. Samples shall be collected from the plant influent (feed water after seeding) and the filter effluent. Samples shall not be collected until the treatment plant has been in operation for a total of 3 theoretical detention times as measured through the filter vessel. For sampling purposes, the time of operation when 3 filtration vessel detention times have elapsed shall be considered time zero. Three feed water samples shall be collected, beginning at time zero, and at 0.5 and 1.0 hours. Three filtered water microsphere or microorganism samples shall be collected, beginning at time zero and at 1.0 and 2.0 hours if grab samples are collected, or if the sampling times are not long enough to result in sampling filtered water during the entire 2 hours of filtered water sampling. The filtered water sampling shall continue for one hour after seeding ceases, to evaluate the capability of the filter to retain large numbers of microspheres or microorganisms even after they are no longer present in the feed water. The exact time of sampling will be recorded so turbidity measurements can be determined at the time of sampling. During the sampling events, the time during which filtered water was sampled shall be noted and turbidity data shall be obtained which are representative of filtered water quality during sampling. If the sampling filter which is used to collect a filtered (treated) water sample has sufficient filtration capacity so that sampling can be conducted with a single sampling filter from time zero to the 2.0 hour sampling time, then a single filtered water sample may be obtained that represents a composite of the filtered water produced during the 2-hour time interval, and collecting three distinct filtered water samples is not required.

For challenge tests carried out with microspheres, volumes of feed water and filtered water to be filtered should be large enough that 30 to 300 microspheres are detected in each seeded feed water sample. Ideally for statistical purposes 30 to 300 microspheres should be detected in each filtered water sample also. If the filtration process is highly efficient for removal of the microspheres, detection of such large numbers in samples of filtered water would not be possible. In such a case, detection of at least 5 microspheres is desirable. If removal is extremely high, detecting 5 or more microspheres in filtered water may not be possible but probably would be indicative of very high log removals of microspheres.

When continuous seeding is practiced, the seeding shall be done for the challenge testing carried out before the filter operation is stopped, but seeding shall NOT be done after the filter is restarted, in the challenge involving stop-start operation in the middle of the run. Likewise, when seeding is by slug doses, seeding shall be practiced during filter operation in the middle of the run, but after the filter is restarted, seeding shall NOT be done. The purpose of restarting the filter and sampling is to assess the possibility for previously-trapped microspheres to pass through the filter during the stress caused by the resumption of flow, and this can not be clearly established if seeding is done after the filter is restarted.

When microspheres are seeded on an instantaneous slug dose basis, dosing shall be done as rapidly as practical, in time intervals as short as several seconds. Slug doses shall be seeded at the beginning of operation, just after flow is turned on in a filter, about mid-way through the filter run, and after the filter has operated long enough to attain 85 to 95 percent of the total available head loss.

For seeding on an instantaneous slug dose basis, the number of microspheres in the concentrated suspension shall be based on an analysis of the concentrated suspension before it was dosed. When the entire production of filtered water is to be collected for sampling, this shall be done from the instant of dosing until a volume of filtered water equal to 20 volumes of the water held in the filter vessel have been collected. The volume of water held in the filter vessel may be calculated as described in section 12.3.3. For a granular media depth filter, the volume of filter media is the volume occupied by solid material only and excludes the volume of void or pore spaces. For example, if the filter vessel volume is 40 liters, and the volume occupied by filter media and support media excluding pore spaces is 10 liters, the net empty volume is 30 liters and a 600 liter sample of filtered water shall be collected and then filtered through a membrane filter as described above in the procedure of Li *et al.*

As an alternative to collecting the entire production of filtered water, a side stream of filtered water may be collected for analysis. The entire volume of the side stream shall be filtered through a membrane filter, as described above. This reduces the volume of water that must be filtered through the membrane. In calculation of log removals, the FTO must adjust the number of microspheres seeded into the feed water in proportion to the volume of the side stream as compared to the full flow of the treatment equipment. For instance if the volume of the side stream was only 10 percent of the volume of the full flow treated, the number of microspheres used for calculation of log removals would equal only 10 percent of the total number of microspheres seeded.

The Testing Organization shall then submit collected water samples to an EPA-accredited analytical laboratory for microbial testing. Microsphere samples shall be analyzed by an EPA-accredited analytical laboratory.

12.5 Evaluation Criteria

Performance evaluation shall be conducted in a number of ways, depending on the types of data collected during testing.

Performance of backwashable depth filtration equipment shall be evaluated in the context of the Manufacturer's statement of performance objectives. Turbidity results will be analyzed to determine the percentage of turbidity data in the range of 0.50 NTU or lower, the percentage between 0.51 NTU and 1.0 NTU, the percentage between 1.1 and 5 NTU, and the percentage that exceeded 5 NTU. The time intervals used for determining filtered water turbidity values shall be the same for all data analyzed, and because continuous turbidimeters are to be used to collect turbidity data, the intervals shall be 1/4, 1/2, or 1 hour. In addition, the highest filtered water turbidity observed each day shall be tabulated. The feed water (if feed water turbidity is continuously monitored) and filtered water turbidity data collected during the 30 minute periods immediately before and following either shutdown and restart without backwashing or shutdown and restart with backwashing shall be presented in tables or graphs.

Electronic particle count data shall be evaluated by calculating the change in total particle count from feed water to filtered water, expressing the change as log reduction. The aggregate of particle counting data obtained during each verification testing period shall be analyzed to determine the median log removal and 95th percentile log removal during that verification testing period. Data for 3 to 7 μm particles shall be analyzed. In addition, data for the 3 to 7 μm particles plus all particles larger than 7 μm shall be analyzed. Because of possible complications in conducting electronic particle counts on feed water, 1 to 4 hour time intervals shall be used for analysis of particle counting data for log reduction of particles. In addition, particle count data for filtered water shall be presented as time series data showing trends of particle counts with passage of time. Data shall be presented showing particle counts in filtered water at time intervals no longer than one hour for the 30 days of Verification Testing. The filtered water particle count data and any available feed water particle count data collected during the 30 minute periods immediately before and following either shutdown and restart without backwashing or shutdown and restart with backwashing shall be presented in tables or graphs.

Data on the density (concentration) of microspheres or protozoa in feed water and filtered water shall be analyzed to determine the median log removal and 95th percentile log removal during that verification testing period. This analysis shall be done separately for each filter operating condition: at start-up after backwashing a dirty filter, mid-way through a run before stopping filter operation and again after restarting the filter (if restart is carried out), and after 85 to 95 percent of terminal head loss has been attained.

13.0 TASK 5: DATA MANAGEMENT

13.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software or manual recording methods, or both, for recording operational parameters for the bag filtration or cartridge filtration equipment on a daily basis.

13.2 Experimental Objectives

One objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Testing Organization provides sufficient and reliable operational data for verification purposes. A second objective is to develop a statistical analysis of the data, as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies."

13.3 Work Plan

13.3.1 Data Management

The following protocol has been developed for data handling and data verification by the Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet

software) as a comma delimited file. These specific database parcels will be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data will be manipulated into a convenient framework to allow analysis of equipment operation. Backup of the computer databases to diskette should be performed on a monthly basis at a minimum.

In the case when a SCADA system is not available, field testing operators will record data and calculations by hand in laboratory notebooks. (Daily measurements will be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook will provide carbon copies of each page. The original notebooks will be stored on-site; the carbon copy sheets will be forwarded to the project engineer of the Field Testing Organization at least once per week. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include a description of the backwashable depth filtration equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project will be set up in the form of custom-designed spreadsheets. The spreadsheets will be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheet. Data entry will be conducted on-site by the designated field testing operators. All recorded calculations will also be checked at this time. Following data entry, the spreadsheet will be printed out and the print-out will be checked against the handwritten data sheet. Any corrections will be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet will be printed out. Each step of the verification process will be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each filtration test run) will be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA-accredited analytical laboratories, the data will be tracked by use of the same system of run numbers. Data from the outside laboratories will be received and reviewed by the field testing operator. These data will be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

13.3.2 Statistical Analysis

Water quality data developed from grab samples collected during filter runs according to the Analytical Schedule in Task 4 of this Test Plan shall be analyzed for statistical uncertainty. The Testing Organization shall calculate 95% confidence intervals for grab sample data obtained during Verification Testing as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants: Requirements For All Studies."

The statistics developed will be helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals. Each of the conditions described in Task 4 (start of run, middle of run before flow stops, middle of run after flow is stopped and restarted, and near end of run approaching terminal head loss) shall be analyzed separately

for 95% confidence intervals. Information on the differences in water quality for the beginning and the end of filter runs would be useful in evaluating the effect of starting operation after backwash and the effect of approaching terminal head loss. Data on microsphere removal in the middle of the run, before and after the filter flow was stopped, can be used to assess the effects of stopping and starting the flow in backwashable depth filtration equipment. Data collected at different times during filter runs, with different head losses, could also be used to evaluate the effect of head loss on filter performance.

14.0 TASK 6: QA/QC

14.1 Introduction

Quality assurance and quality control of the operation of the backwashable depth filtration equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instruments within the ranges specified by the manufacturers or by *Standard Methods*. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 Work Plan

Equipment flow rates and associated signals should be documented and recorded on a routine basis. A routine daily walk-through during testing will be established to verify that each piece of equipment or instrumentation is operating properly. In-line monitoring equipment such as flow meters, etc. will be checked to confirm that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

14.4 Daily QA/QC Verifications

- In-line turbidimeters flowrates (verified volumetrically over a specific time period)
- In-line turbidimeter readings checked against a properly calibrated bench model
- Batch and in-line particle counters flowrates (verified volumetrically over a specific time period).

14.5 Bi-weekly QA/QC Verifications

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

14.6 QA/QC Verifications at Start of Each Testing Period

- In-line turbidimeters (clean out reservoirs and recalibrate)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)
- Particle counters (perform microsphere calibration verification)

14.7 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of raw water and filtered water quality are described in the section below. In-line equipment is recommended for its ease of operation and because it limits the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. In-line equipment is recommended for measurement of turbidity and for particle counting for feed water and is required for measurement of turbidity and for particle counting for filtered water.

14.7.1 pH

Analysis for pH shall be performed according to *Standard Methods* 4500-H^+. A three-point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

14.7.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Methods* 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1°C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1°C to +51°C, subdivided in 0.1° increments, would be appropriate for this work.)

14.7.3 Turbidity Analysis

Turbidity analyses shall be performed according to *Standard Methods* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters shall be used for measurement of turbidity in the filtrate waters, and either an in-line or bench-top may be used for measurement of the feedwater.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring equipment.

14.7.3.1 Bench-Top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of equipment operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples that cause the vial to fog preventing accurate readings, allow the vial to warm up by submersing partially into a warm water bath for approximately 30 seconds.

14.7.3.2 In-Line Turbidimeters. In-line turbidimeters are required for filtered water monitoring during verification testing and must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow rate should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

14.7.4 Particle Counting

In-line particle counters shall be employed for measurement of particle concentrations in filtrate waters. However, either a bench-top or an in-line particle counter may be used to measure particle concentrations in the feedwater, concentrate (where applicable) and pretreated waters (where applicable). Laser light scattering or light blocking instruments are recommended for particle counting during verification testing. However, other types of counters such as Coulter counters or Elzone counters may be considered for use if they can be configured to provide continuous, in-line monitoring for the filtrate product water stream. The following discussion of operation and maintenance applies primarily for use of laser light blocking instruments.

The following particle size ranges shall be monitored by both in-line and bench-top analytical instruments during the verification testing:

- 2-3 μm
- 3-5 μm
- 5-7 μm
- 7-10 μm
- 10-15 μm
- > 15 μm

The Field Testing Organization shall be required to document any problems experienced with the monitoring particle counting instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

Use of particle counting to characterize feedwater and filtered water quality is required as one surrogate method for evaluation of microbiological contaminant removal.

14.7.4.1 Bench-Top Particle Counters. All particle counting shall be performed on-site. The particle sensor selected must be capable of measuring particles as small as 2 μm. There should be less than a ten percent coincidence error for any one measurement.

Calibration. Calibration of the particle counter is generally performed by the instrument manufacturer. The calibration data will be provided by the manufacturer for entry into the software calibration program. Once the data has been entered it should be verified using calibrated commercially-available particle standards or methods. This calibration should be verified at the beginning of each Verification Testing period.

Maintenance. The need for routine cleaning of the sensor cell is typically indicated by: 1) illumination of the sensor's "cell" or "laser" lamps, 2) an increase in sampling time from measurement to measurement, or 3) an increase in particle counts from measurement to measurement. During the ETV testing, the sensor's "cell" and "laser" lamps and the sampling time will be checked periodically. The number of particles in the "particle-free water" will also be monitored daily.

Particle-Free Water System. "Particle-free water" (PFW) will be used for final glassware rinsing, dilution water, and blank water. This water will consist of de-ionized (DI) water that has passed through a 0.22-μm cartridge filtration system. This water is expected to contain fewer than 10 total particles per mL, as quantified by the on-site particle counter.

Glassware Preparation. All glassware used for particle counting samples shall consist of beakers designed specifically for the instrument being used. Glassware will be cleaned after every use by hand washing using hot water and laboratory glassware detergent solution followed by a triple PFW rinse. Sample beakers will then be stored inverted.

Dedicated beakers will be used at all times for unfiltered water, diluted unfiltered water, prefiltered water (if prefiltration is used), filtered water, and PFW. When several samples are collected from various equipment sampling points during one day, the appropriate beakers will be hand-washed as described above, and then rinsed three times with sample prior to collection.

Other materials in contact with the samples, including volumetric pipettes, volumetric flasks, and other glassware used for dilution, will also be triple-rinsed with both PFW and sample between each measurement.

Sample Collection. Beakers should be rinsed with the sample at least three times prior to sample collection for particle counting. Sample taps should be opened slowly prior to sampling. Sudden changes in the velocity of flow through the sampling taps should be avoided immediately prior to sample collection to avoid scouring of particles from interior surfaces. A slow, steady flow rate from the sample tap will be established and maintained for at least one minute prior to sample collection. The sample will be collected by allowing the sample water to flow down the side of the flask or beaker; thereby minimizing entrainment of air bubbles.

Dilution. The number of particles in the raw and pretreated waters (where applicable) is likely to exceed the coincidence limit of the sensor. If so, these samples will be diluted prior to analysis. In all cases, PFW will be used as dilution water.

When necessary, dilutions will be performed as follows:

- Dilution water will be dispensed directly into a 500-mL volumetric flask;
- A volumetric pipette (i.e. 10-mL for a 50:1 dilution) will be used to collect an aliquot of the sample to be diluted (stock);
- The appropriate volume of the stock will be slowly added to the volumetric flask containing the dilution water;
- The volumetric flask will be slowly filled to the full-volume etch with dilution water;
- The volumetric flask will be inverted gently and then its contents will be poured slowly into the appropriate 500-mL flask for analysis.

During each of the above steps, care will be taken to avoid entrainment of air bubbles; thus, samples and dilution water will flow slowly down the side of containers to which they are added. Excessive flow rates through pipette tips, which can cause particle break-up, will be avoided by use of wide-mouth pipettes. Sample water will be drawn into and out of pipettes slowly to further minimize particle break-up.

Actual particle counts in a size range for diluted samples will be calculated based on the following formula:

$$Sample\ Particle\ Concentration = \frac{\{MP - (1 - X) \times PF\}}{X}$$

where MP is the measured particle concentration (particles per mL) in the diluted sample, PF is the measured particle concentration (particles per mL) in the particle-free water, and X represents the dilution factor. For a 25:1 dilution, the dilution factor would be 1/25, or 0.04. The expression for the dilution factor is provided by the following equation:

$$Dilution\ Factor = X = \frac{Volume\ Sample}{Addition\ of\ Volume\ Sample + Volume\ Dilution\ Water}$$

Particle Counting Sample Analysis. To collect samples for particle counting, at least 200 mL of each water sample to be counted (diluted or not) should be collected in the appropriate beaker. The beaker will be placed into the pressure cell and counting will take place in the "auto" mode of the instrument. Four counts will be made of each sample. The first count will serve to rinse the instrument with the sample; data from this count are discarded. Data from the subsequent three counts will be averaged, and the average value will be reported as the count for that sample.

14.7.4.2 In-Line Particle Counters. Any in-line particle sensors selected for use must have capabilities for measurement of particles as small as 2 μm and have a coincidence error of less than ten percent. The particle counter manufacturer shall provide data and methods that the in-line particle sensors meet these criteria or an independent third party shall verify the in-line particle sensor meets the above criteria. The particle counter manufacturer shall provide the methods for demonstration of coincidence error.

The sensors of the in-line units must also be provided with a recent (two months before the start of testing) manufacturer calibration. The calibration shall be verified by measurement of the individual and cocktail suspensions of the monospheres as described for the batch counter; however, in this case the samples must be fed in-line to the counters.

No dilution of the filtered water samples will be conducted. The data acquired from the counters will be electronically transferred to the data acquisition system. If it is known that a particular sensor will not be used for a period of several days or more, refer to the manufacturer recommendations for an appropriate storage protocol.

14.8 Chemical and Biological Samples Shipped Off-Site for Analyses

14.8.1 Organic Parameter: Total Organic Carbon and UV_{254} Absorbance

Samples for analysis of TOC and UV_{254} absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4^{o}C to the analytical laboratory. These samples shall be preserved, held, and shipped in accordance with Standard Method 5010B. Storage time before analysis shall be minimized, according to *Standard Methods*. TOC is a required sampling parameter. UV_{254} absorbance is an optional sampling parameter.

14.8.2 Microbial Parameters: Total Coliform (Optional) and Algae

Samples for analysis of total coliform (TC) shall be collected in bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped with an internal cooler temperature of approximately 4^{o}C to the analytical laboratory. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited analytical laboratory within the time specified for the relevant analytical method. The laboratory shall keep the samples at approximately 4^{o}C until initiation of analysis. TC densities shall be reported as most probable number per 100 mL (MPN/100 mL) or as total coliform densities per 100 mL. TC is an optional sampling parameter.

Algae samples shall be preserved with Lugol's solution after collection, stored and shipped in a cooler at a temperature of approximately 4°C, and held at that temperature range until counted.

14.8.3 Inorganic Samples

Inorganic chemical samples, including, alkalinity, hardness, iron, and manganese, shall be collected, preserved and held in accordance with *Standard Methods* 3010B, paying particular attention to the sources of contamination as outlined in Standard Method 3010C. The samples shall be refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C during shipment. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

14.8.4 Microspheres

The membrane filters used for obtaining microsphere samples shall be refrigerated at approximately 2 to 8°C immediately upon collection. Such samples shall be shipped in a cooler and maintained at a temperature of approximately 2 to 8°C during shipment and in the analytical laboratory, until they are analyzed. This is done to minimize microbiological growth on the membranes.
Recovery of microspheres from suspensions held in glassware shall be evaluated by preparing a suspension of microspheres in which the number of microspheres used to make the suspension is estimated, based on either the weight of dry microspheres or the volume of microspheres in liquid suspension as provided by the supplier. After the suspension is prepared and mixed until it is homogeneous, five aliquots shall be taken and counted in the hemacytometer. After the microsphere density (concentration) has been calculated, aliquots of the suspension shall be diluted and filtered through polycarbonate membrane filters having 1 μm pore size. The elution and concentration steps described in Task 4 shall be followed, and the microspheres shall be counted in a hemacytometer. This shall be done five times, so that statistics can be developed on the recovery of microspheres in the sampling procedure.

As a check on possible interference from fluorescing organisms in the feed water, during each Verification Testing run in which fluorescent microspheres are used, a sample of feed water with no seeded microspheres shall be filtered through a polycarbonate membrane, and the particulate matter on the membrane shall be concentrated using the procedures for microsphere analysis, and the concentrate shall be examined in a hemacytometer by microscope, with UV illumination. If no objects of the size and shape of the microspheres are seen to fluoresce, displaying the same color as the microspheres, then fluorescent objects of the proper color seen in samples with seeded microspheres can be considered to be microspheres.

Microspheres may adhere to surfaces of tanks, vessels, and glassware. All glassware, holding tanks, and membrane filter manifolds must be cleaned between seeding events or sampling events.

15.0 OPERATION AND MAINTENANCE

The Field Testing Organization shall obtain the Manufacturer-supplied O&M manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for O&M Manuals for backwashable depth filter equipment.

15.1 Maintenance

The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- motors
- valves
- mechanisms involved in washing the filter
- equipment used for cleaning filter media
- pressure filter vessel opening mechanisms, if provided
- instruments, such as turbidimeters
- water meters, if provided

The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as tanks and basins.

If prefiltration equipment is used, the manufacturer should provide the same sort of information for that equipment as the information described above.

15.2 Operation

The manufacturer should provide readily understood recommendations for procedures related to proper operation of the equipment, both for filtration equipment and for prefiltration equipment, if that also is used. Among the operating aspects that should be discussed are:

Equipment Compatibility:

- compatibility with chemical disinfectants
- compatibility with oxidants

Filtration:

- control of filtration rate
- observation and measurement of head loss during filter run

Filter backwashing:

- criteria for determining end of filter run
- start of backwash
- appropriate backwash rates
- use of auxiliary water scour (surface wash) or air scour, if provided
- can rate of flow of backwash water be measured and controlled?
- duration of filter washing
- procedure for determining when to end backwash
- return of filter to service
- does equipment provide for filter-to-waste operation at start of filter run after the filter has been backwashed?
- can the operator stop and re-start the filter without backwashing it, or does the equipment automatically backwash the filter if flow is stopped and the filter is re-started?

Monitoring and observing operation:

- filter vessel inlet pressure
- filter vessel outlet pressure
- filter head loss
- raw water turbidity or pretreated water turbidity
- filtered water turbidity
- rate of flow
- what to do if turbidity breakthrough occurs

The manufacturer should provide a troubleshooting guide for filtration equipment and for prefiltration equipment, if the latter was also provided. The guide should be a simple check-list of what to do for a variety of problems including:

- no raw water (feed water) flow to plant
- can't control rate of flow of water through equipment
- filter can't be backwashed or backwash rate of flow can't change
- no reading on turbidimeter
- automatic operation (if provided) not functioning
- filtered water turbidity too high
- excessively high head loss through filter after dirty filter backwashed
- filter head loss builds up too quickly during a run
- no head loss readings
- valve stuck or won't operate
- clogged prefiltration equipment (if used)
- no electric power

The following are recommendations regarding operability aspects of backwashable depth filter equipment. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of equipment testing when the testing is done under the ETV Program.

During Verification Testing and during compilation of historical equipment operating data, attention shall be given to equipment operability aspects. If prefiltration equipment is also used, operability of that equipment shall also be discussed. Among the factors that should be considered are:

- can both influent pressure and effluent pressure be measured at filter vessel?
- is rate of flow of raw (feed) water measured?
- can raw (feed) water turbidity be measured continuously?
- can filtered water turbidity be measured continuously?
- can filter bags or cartridges be replaced easily if this becomes necessary?
- does operator have a simple, reliable way of knowing the new filter bag or cartridge is installed and seated properly in the filter vessel?
- comment on operability of filtration equipment with and without use of prefiltration equipment, if filtration equipment was operated in both modes
- can operator observe backwash of granular media?
- how can operator check on condition and depth of granular media?
- susceptibility of prefiltration equipment (if provided) to clogging
- can filter cleaning be done automatically?
- if automatic cleaning or backwashing is provided, could it be initiated by:
- reaching a set value for head loss?
- reaching a set value for filtered water turbidity?
- reaching a set value for time in operation?
- does remote notification to operator occur when cleaning happens?
- does cleaning restore filter to original clean bed head loss or does higher head loss for clean filter indicate progressive clogging of filter?
- how does the operator know that the backwash cleaned the filter satisfactorily?
- can volume of water used for cleaning filter be measured?
- can the rate of flow during cleaning be controlled?
- is backwash duration (time) variable?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Task 3: Operating Conditions and Treatment Equipment Performance, in the Backwashable Depth Filter Test Plan.

16.0 REFERENCES

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Table 1. Generic Schedule for Verification Testing of Backwashable Depth Filters

Test Period	Initial Operations, Estimated Time	Verification Testing, Minimum Required Time
#1	1 - 6 weeks	30 days or more
#2 (optional)	1 - 3 weeks	30 days or more
#3 (optional)	1 - 3 weeks	30 days or more
#4 (optional)	1 - 3 weeks	30 days or more

Table 2. Water Quality Sampling and Measurement Schedule	
Sample or Measure For:	Minimum Frequency:
Temperature	Daily
pH	Weekly
Total alkalinity	Desired weekly but optional
Hardness	Desired weekly but optional
Total organic carbon	Desired weekly but optional
Turbidity	Daily at bench to check continuous turbidimeters
Continuous turbidity monitoring	Use data at 1/4, 1/2, or 1 hour for calculations of long-term performance. Also note maximum turbidity observed each day.
Iron	Once each testing period or weekly if present in concentration of 0.3 mg/L or greater
Manganese	Once each testing period or weekly if present in concentration of 0.05 mg/L or greater
Total coliform bacteria	Desired twice per week, at least 2 days apart, but optional
Algae, number and species	Weekly; 3 times per week if algae cause shorter filter runs.
UV_{254} absorbance	Desired weekly (when sample for TOC taken) but optional
For schedule for microspheres, particle counting, and *Cryptosporidium*, see Task 4. Collection of samples at times other than those specified for the minimum frequency may be appropriate to show the full range of feed water treated, if rapid and significant changes in feed water quality occur during Verification Testing.	

Table 3. Analytical Methods			
Parameter	Facility	*Standard Methods*[1] number or Other Method Reference	EPA Method[2]
Temperature	On-Site	2550 B	
pH	On-Site	4500-H^+ B	150.1 / 150.2
Total alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Total organic carbon	Lab	5310 C	
Turbidity	On-Site	2130 B / Method 2	180.1
Particle counts (electronic)	On-Site	Manufacturer	
Iron	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Manganese	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Algae, number and species	Lab	10200 and 10900	
UV_{254} absorbance	Lab	5910 B	
Total coliform	Lab	9221 / 9222 / 9223	
Cryptosporidium	Lab	NSF and EPA may consider alternative methods if sufficient data on precision, accuracy, and comparative studies are available for alternative methods.	EPA 1622, EPA 1623
Microsphere counts	Lab	Li *et al.*,1997	

Notes:
1) Standard Methods Source: 20th Edition of Standard Methods for the Examination of Water and Wastewater, 1999, American Water Works Association.
2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Table 4. Backwashable Depth Filtration Equipment Description and Operating Data	
Operating Data	Action
Feedwater Flow and Filter Flow	Check and record twice per day, adjust when >10% above or below goal. Record both before and after adjustment.
Filter Head Loss (filter inlet pressure and filter outlet pressure)	Record initial clean bed total head loss at start of filter run and record total head loss two times per day.
Backwashing	Record time, date, and feed water or filtered water meter reading at time of each backwash; and calculate total water produced in the filter run. Record terminal head loss at end of run just before filter was shut off and backwashed. Note reason for backwashing, rate of flow for backwash, and volume of wash water used.
Electric Power	Record meter reading once per day.
Hours operated per day	Record in log book at end of day or at beginning of first shift on the following work day. (Around-the-clock operation is recommended).
Filtered Water Production	Calculate gallons or cubic meters of water produced per filter run, and total water produced by the filtration equipment each day it is operated.
Log of events in watershed	Record occurrence of storms, construction activities, snowmelt, or other activities that could influence source water quality in log book at end of day or at beginning of shift on following work day.
Provide a complete description of the equipment as required in Task 3.	

Table 5. Challenge Test and Particle Counting Schedule	
Particle Counting	
Feed water	continuous or count 8 samples/day, if particle counting of feed water done on grab (batch) samples
Filtered water	continuous particle counting required
Analysis of Feed Water and Filtered Water for Microspheres or Challenge Organisms (or both)	
1. start equipment after filter was backwashed	1. after equipment started up and 3 filter vessel volumes treated
2. midway in run, as indicated by filter head loss	2a. sample before stopping operation of filter
	2b. sample after filter stopped and restarted again, if filter can be restarted without backwashing
3. near end of run at 85% to 95% of total filter run head loss	3. sample before stopping operation of filter
For microsphere or challenge organism testing, must do two separate runs after the filter has been operated and backwashed.	